Sewage Research

RESEARCH IN SEWAGE CHEMISTRY, SEWAGE TREATMENT AND STREAM POLLUTION

A CRITICAL REVIEW OF THE LITERATURE OF 1935

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Chemistry and Biology

Much of the outstanding research work of the year 1935 in the general field of chemical, bio-chemical, and biological theories of sewage disposal has dealt with the details of the mechanisms and reactions involved. The progress reported along various lines gives promise of settling controversial and poorly understood details of fundamental theory and points the way toward the substitution of the results of exact, even though difficult, experimental investigation for general hypotheses and analogies upon which reliance has been placed in the past.

Clarification and Oxidation.—Outstanding in this field is the work of Theriault and associates (1, 2, 3, 4) leading to the proposal that activated sludge, bacterial slimes and the *schmutzdecke* of the slow sand filter in water purification are all of zeolitic composition and nature and that their primary function in each case is adsorption of basic organic material through the well known process of base exchange.

Theriault defines clarification, as distinguished from all the other processes of purification and of oxidation, as that process which characterizes biological treatments in general, but particularly activated sludge treatment, whereby the supernatant liquor is apparently purified to a high degree within a relatively short space of time, usually reckoned in minutes. Such a rapid rate of purification is incompatible with our experimental knowledge of rates of biological oxidation and upon investigation is always found to be the result of a separation of the dissolved and suspended impurities from the liquor rather than a true oxidation process.

Reviewing the various "explanations" of clarification, Theriault examines and rejects on adequate evidence the theories of electrostatically charged colloids, of surface attraction, of bio-precipitation, of enzymatic precipitation or solution, and of the primary influence of protozoa as clarifying agencies. He accepts, as most nearly adequate of the various earlier views, that of Dunbar in which adsorption by the bacterial slime plays a primary role. He holds it essential that atten-

tion be focused upon the nature of the slime or floc with the purpose of more definitely defining the mechanism of the adsorption.

Results of existent analyses of the activated sludge floc and of various slimes suggest that the inorganic portion of the gelatinous matrix has a chemical composition which would include it within the category of a zeolite, *i.e.* a hydrated double silicate of a monobasic and a tribasic metal. More refined analyses made by Theriault on the activated sludge floc carefully freed from extraneous matter by long time "purification," corrected for the chemical content of the ash of the embedded bacteria, tended strongly to confirm Theriault's hypothesis of the zeolitic nature of the matrix.

In addition to possessing the proper chemical composition, the zeolite theory demands that the activity of the matrix shall simulate that of the known zeolites. To test this analogy, Theriault and McNamee (3) investigated the data of Parsons and Wilson on equilibria between activated sludge and various concentrations of organic matter in the liquor, with the help of the theoretical formula of Freundlich for equilibria in such systems. A satisfactory agreement was obtained through a range of concentrations. Even more satisfactory was the agreement obtained by using a preparation of activated sludge which had been dried at 100° C. and brought to equilibrium in solutions of various concentrations of ammonia. Perhaps the most conclusive point was the demonstration that this dried material, after having come to equilibrium in ammonia solution, could be regenerated by the use of a dilute solution of sodium chloride. Base exchange between the sodium and calcium was also demonstrated. The author concludes that "The clarification of a sewage is accomplished by the adsorption of organic matters on the sludge zeolite, without accompanying oxidation or bacterial intervention. The time required for reaching an equilibrium with the organic matters of sewage is about 30 minutes, after which further adsorption will depend upon the rate of bacterial action."

Turning next to the oxidation phase of purification, several reports have appeared of more than usual interest. In a laboratory study of biological oxidation of effluents from beet sugar factories Richards and Cutler (5) find that the rate of oxidation of carbohydrates in solution is influenced by the amount of available nitrogen.

Holderby and Lea (6) have dealt with this same point in more detail and have arrived at a general conclusion that in so far as the oxidation of sugars is concerned the rate of oxidation is critically dependent upon the ratio of total organic nitrogen to total organic carbon. Their results are remarkably in line with similar results reached by Eldridge (7) although the latter attributed the effect noted to an increase in bacterial seeding. Holderby and Lea used sterile sewage and uniform seedings throughout. Unfortunately their experiment was not planned to distinguish between the two variables, the nitrogen-carbon ratio and sugar concentration. A critical study of their data suggests that possibly it is the latter variable that is more largely responsible.

The phosphorus requirements of trickling filters have been investigated on a laboratory scale by Jenkins (8) using glass tubes containing glass beads. The experiments demonstrated an influence of phosphorus on the rate of oxidation of carbohydrates and other organic matter present in the press water of a sugar factory. Phosphorus in the form of K_2HPO_4 was more available for biological activities than the organic phosphorus compounds present in the waste. Excess of phosphate passed through the filters unchanged. Increasing the phosphate content caused an increase in acidity, due to the removal of ammonia and the liberation of free HCl.

Further experiments made at the Rothamsted Experimental Station (9) on mixtures containing 1 per cent by volume of milk, applied at a rate of 100 gallons per day per cubic yard of filtering materials, showed that active biological film was rapidly formed during the first few days and at the same time the efficiencies of the filters increased. After the filters had been in operation for about two weeks they effected a 5-day B.O.D. reduction of 80 to 90 per cent.

The effect of activated sludge on the oxidation of sugars, fats, fatty acids, amino acids, proteins and phenols was studied under the direction of Topley (9) in the Barcroft apparatus at 24° C. Many of the sugars, such as fructose and maltose, were oxidized more rapidly than glucose and others oxidized less rapidly, but activated sludge promoted the oxidation of all the substances examined. Phenol in concentrations of 0.1 per cent inhibited oxidation, but in smaller concentrations it was readily oxidized.

Among the minor agencies affecting bacterial oxidation, favorably or otherwise, the concentration of iron salts injurious to trickling filters has been investigated by Singleton and Frith (10). Adding 300 lb. of chlorinated copperas per mill. gal. to the influent of a trickling filter caused a rapid disappearance of the film, while the effluent increased to a B.O.D. of about 125, accompanied by high turbidity and colloidal iron color. The damage is not ascribed to excess chlorine since no residual was present. After stopping and applying untreated Imhoff tank effluent for two days a good film was forming, with a drop in turbidity to normal. The rapid action was probably due to the acidic nature of the iron salt.

Theriault, Butterfield and McNamee (11) studying catalysis of air oxidations by iron salts, phosphates and pyrophosphates found negative results in the range of temperatures from 20 to 50° C. and at pH values within the physiological range, whenever bacteria were excluded from the glucose solution used. Iron pyrophosphate mixtures were not effective in stimulating the oxidations accomplished by bacteria alone or by symbiotic growths of bacteria and plankton. Numerous varieties of bacteria exist which are quite indifferent to the presence of iron pyrophosphates. The authors expressed the view that assumptions regarding the presence of specialized intracellular catalysts may be unnecessary in the interpretation of the known facts regarding biological oxidations.

Experiments conducted by Key (12) concerning the effect of gas-house liquors on trickling filters showed that the presence of phenol was of minor importance, as far as oxygen absorption was concerned, if the waste was mixed with sewage. Thiocyanite passed through the filter unchanged at first but the filter soon acquired the power to deal with it and after a week's operation it was absent from the effluent. Either a special type of organism developed capable of oxidizing thiocyanite, or a gradual change was taking place in the organisms present enabling them to cope with the material.

Digestion.—Segregated, finely divided solids digest more rapidly than coarse material, but Fair and Moore (13) found that when sewage solids are mechanically disintegrated the difference between normal and comminuted sewage solids is small as measured by the rate and completeness of gas production. They call attention to the compacting of comminuted solids and suggest that agitation during digestion may utilize the surfaces created by disintegration and yield more significant differences than those so far observed.

High and low temperature digestion continues to interest engineers and operators. Granqvist (14) reporting results of one year's operation and experimentation in Helsingfors, Finland, states that heating sludge to 110° F. produced twice as much gas per cubic content as heating to 75 to 80° F. The extra cost of heating was such that, in practice, the economic advantage was lost. The experiments are of particular interest because the tanks were insulated at the bottom and sides with cork.

Rudolfs and Miles (15) were unable to produce thermophilic sludge from digesting mesophilic sludge on a semi-plant scale, while fresh solids were added daily. Operation difficulties, scum formation, objectionable odors and little gas production resulted. When fresh mesophilic sludge was subjected to higher temperatures and allowed to digest before fresh solids additions were made, Cleary (16) found that high temperature digestion proceeded rapidly. His studies suggest the advantages of consecutive (two-stage) digestion, using a primary period of thermophilic and a secondary of mesophilic decomposition. Consecutive digestion required twelve days, with a greater destruction of organic matter and subsequent acceleration of gas production, than single-stage digestion. Correlation between reduction in volatile matter and time of digestion is illustrated.

Studies by Ardern and Lockett (17) at different temperatures led to the conclusion that digestion of activated sludge alone was not attractive at high or low temperature, mainly on account of low gas yields but also because of difficulties in maintaining proper pH values. The material should be mixed with fresh solids. Proper seeding is one of the essential requirements. Young and Philips (18) found that the same quantities of gas were produced at 84° F. as at 94° F. so that it was questionable whether the higher temperature was of advantage. At the higher temperature a gradual change in bacterial flora may be obtained without affecting adversely thermophilic conditions.

The question of the value of stirring the contents of digestion tanks has not been settled. Proponents of rapid stirring claim considerable advantages. Granqvist (14) using paddles and a Pruss pump in different tanks concludes that stirring mechanisms in tanks heated to 75 to 80° F. has no economic value.

In connection with studies on the effect of milk waste on the activated sludge process Eldridge, Mallmann and Robinson (29) determined the utilization of carbohydrates and proteins by the organisms present. They found that lactose was rapidly acted upon, but when added alone, it caused a decrease in sludge solids and a bulking condition of the sludge. The sludge organisms acting on carbohydrates remained active for several days. The first stage of protein utilization was attended by ammonia and nitrate production, with some loss of N during the process. Protein treatment increased the density and weight of the sludge, while fat caused bulking.

The possibility of stimulating the gross activities of the organisms present in activated sludge, and especially those which are assumed to be of greatest importance, without exactly knowing what they are and how they behave, is rather alluring. The effect of iron and aluminum on the activated sludge process has been variously described by a number of investigators who have advanced various theoretical considerations.

Nesmejanoff (30) conducted a series of laboratory experiments with iron and aluminum salts. He concluded that addition of iron, combined with strong electrolytic acids, in quantities of 8.7 p.p.m. and greater, was definitely retarding, probably caused by hydrolysis of the iron, thus producing a change in the hydrogen-ion concentration. When the iron is combined with weak acid ions the iron salts are neither detrimental nor stimulating. The same holds for aluminum salts. He doubts that iron salts have any real effect. It is possible that the findings of this investigator are due to the fact that comparatively large quantities of salts were used. Sartorius (21) working with 5-liter laboratory tanks and aerating with paddles, found that floc formation and purification were disturbed by moderate quantities of salts (NaCl, $NaSO_4$, etc.) and the different cations acted differently. Much improvement followed the application of iron salts, even in very small quantities, and the addition of phenol brought about some improvement. Chlorphenol was very detrimental. In all cases large doses were detrimental.

Knechtges, Dawson and Nichols (19) report that mixing of packinghouse solids with domestic sewage sludges in no way hinders the digestion, up to 50 per cent packinghouse sludge by volume. The lipids digest to gas more completely than the bulk of total solids. The curious fact that in some unseeded mixtures no drop in pH occurred is not explained by the authors.

Studies dealing with specific bacteria and with nitrification in soils have been reported, but isolations of nitrifying organisms from activated sludge have not frequently been made. Miss Winograsky (20)

has isolated several organisms belonging to two general groups; nitrosobacteria and nitrobacteria, which are briefly described. In the first group one free form, *Nitrosomonas,* and four colony forming organisms remained constant for two years. Three of the colony forming organisms, *Nitrosogloea merismoides, N. schizobacteroides, N. membranacea,* are zoogleal forms, while the fourth isolated, *Nitrociptis,* occurs frequently in arable soils. The two nitrobacteria isolated were vegetative colony forming organisms. It is of interest that the intensity of oxidation activities of these different organisms was enhanced by iron when the dosage could be assimilated. Sartorius (21) inoculated activated sludge with a number of organisms and observed that inoculation with root bacilli, similar to that used to stimulate the growth of legumes, stimulated oxidation. *B. fluorescens* and *B. proteus* were more effective, while *B. coli* and *B. pyocyanus* had the least effect.

Butterfield (22) correlated the presence of large zoogleal masses in activated sludge with the efficiency of the process. Following this he isolated, studied the properties and identified these masses as *Zooglea ramigera.* His technique and procedure are interesting. After attempting to grow the organism on solid media (agar and gelatin), and later in broth without success, he purified clumps of zoogleal masses by washing with sterile nutrient broth diluted with 90 per cent water. This freed the zoogleal masses from extraneous matter and contaminating bacteria. These purified masses were than again planted on standard agar plates, and in lactose broth. No growth appeared on the plates while excellent results were obtained in the lactose broth tubes. The cultural characteristics of the isolated organism were determined (23). The main points of interest were optimum pH for growth 7.0 to 7.4, optimum temperature 28 to 30° C. and strictly aerobic requirements.

After isolation, pure cultures in a synthetic medium of broth and dilution water produced a good floc under moderate aeration, but under normal aeration the floc tended to break up and disperse. This indicated the need of a "framework" for the floc. Very short cotton and asbestos fibers were tried and it was found that the floc adhered tenaciously to the cotton but not to the asbestos. By successive aeration, settling and decanting a sludge was produced of about 2000 p.p.m. suspended matter. Experiments then showed that this floc, with aeration, would remove from 66 to 76 per cent of the oxidizable organic matter of the synthetic medium. Using the same synthetic medium, the cotton fibers and none of the zoogleal organisms, the oxygen demand was reduced only about 5 per cent. Further tests were made in which the synthetic medium was replaced with sterile domestic sewage. Floc formation again took place with oxygen demand reduction of from 64 to 76 per cent.

Experiments using the zoogleal bacteria and the ciliated protozoon *Colpidium,* demonstrated that this organism exerted only a very slight effect on the quantity of oxidizable material removed, although the liquid was much clearer. This appears to agree with the findings of

Ardern and Lockett, that protozoa are not important in purification by activated sludge although they may aid in the production of a more highly clarified effluent (24). Although the oxidizable material in sewage was reduced by zoogleal bacteria, tests indicated that there was no oxidation of nitrogen compounds to nitrite or nitrate.

Dienert (25) states that the clarification of sewage is the result of the coagulation of colloidal material by various bacteria which fix themselves on certain particles such as cellulose, or on glass when in the absence of other materials. Oxygen is indispensable for these coagulating bacteria, and contact with CO_2 reduces their coagulating power. The author has obtained several kinds of coagulating bacteria from activated sludge, which could not be isolated by growth on gelatine or agar. On cultivation and breaking up of clumps in distilled water the suspension was slightly electropositive, but the same culture grown in peptone broth was electronegative. When the culture was in contact with glass, the positive charge of the bacterial membrane was neutralized, but when detached the culture regained its positive charge. The coagulating bacteria develop on the surface of the coagulated particles, and are found in activated sludge and in slow sand filters.

Aeration.—The relative rates of solution of atmospheric oxygen from surface contact and from air bubbles are of practical importance, especially in the activated sludge process. Scouller and Watson (26) and Scouller and Nixon (27) bubbled known volumes of air through deaerated distilled water in an hourglass-shaped glass vessel. They found that the top portion of water always contained a greater percentage of oxygen than the bottom. The authors conclude that the oxygen absorbed per unit of bubble surface per 24 hr. was three times that absorbed through the same area of exposed water surface. The conclusion that oxygen requirements of activated sludge plants were so large that they could not be satisfied by surface aeration was questioned in the discussion of this paper.

It is difficult to estimate dissolved oxygen in an aeration plant when quantities of activated sludge are present, because of the oxygen demand of the sludge liquid. Watson (28), experimenting on a plant scale, concluded that the rate of absorption of oxygen by activated sludge depends upon the liquid undergoing purification. The stronger and more colloidal the sewage the greater is the energy required to dissolve a given quantity of oxygen in the liquid by mechanical aeration. He suggests, therefore, that treatment in a series of tanks would probably be a distinct advantage, with aeration intensified at the commencement of the purification.

Experiments on the effect of the presence of activated sludge on the rate of oxidation by air have been continued in this country and abroad. Earlier English experiments had indicated that the rate of oxidation of a mixture of crude sewage and activated sludge is much greater than the sum of the rates for the constituents treated separately. This conclusion has been confirmed by the Water Pollution Research Board (9) who report that the rate of oxidation of a mixture

of activated sludge and treated effluent is greater than the sum of the rates for the sludge and effluent aerated separately. When activated sludge was mixed, without aeration, with several hundred times its volume of crude sewage and then separated by centrifuging, the activity of the sludge in promoting oxidation of sewage was greatly reduced. Aeration for several hours was necessary to restore the activity of the sludge.

Granqvist (14), at Helsingfors, compared four different methods of aeration in different tanks receiving the same sewage. He found that the detention time and air consumption depended in large measure upon the type of sewage. In one tank reaeration was continuous, in one tank partial and in two tanks no reaeration was given. The author could find no advantage in reaeration. Aeration time averaged from 6.7 to 12.8 hours, while air consumption averaged roughly from 1 to 2 cu. ft. per gallon of sewage. B.O.D. of raw sewage averaged 405 p.p.m. and the effluent from the settling tanks, which was treated in the aeration tanks, 264 p.p.m. It is possible that the comparatively large volume of air used in conjunction with relatively long aeration time made it unnecessary to reaerate the sludge mixtures.

Methods of Analysis.—Gradually the methods of analysis employed in sewage treatment and research are being improved. This year the Committee of the Sewage Works Federation on Sewage Analyses has presented a revision of the Standard Methods (31), written primarily for the use of chemists and not with the idea that the procedure would be sufficiently detailed for use by the untrained man. The presentation, including many of the important analyses for plant control and research, is a step in advance over the old Standard Methods.

The determination of suspended solids in sewage by observing the extent of light absorption as registered in a photoelectric cell has been reported upon by Holmes (32). He finds a nearly theoretical relationship between suspended solids and absorption which is more nearly perfect as the degree of comminution of the solids is increased. Setter (33) has developed a useful method of determining suspended solids in activated sludge. Using a high speed centrifuge under standard operating conditions he has been able to work out a satisfactory straight-line relation between suspended solids in p.p.m. (x) and volume of sediment in per cent (y), as follows.

$$x = 600y - 150$$

Kessler and Nichols (34) call attention to Nordell's experiments at Milwaukee in 1917, and have prepared an excellent paper on the oxygen utilization of activated sludge. On account of Nordell's early work they have applied the term " Nordell Number " to the rate of oxygen utilization expressed in mg. per liter per hour.

While the study of sewage-sludge mixtures involves the ordinary determination of dissolved oxygen, the introduction of copper sulphate to stop the biological action at a certain time and cause rapid settlement of the sludge is of importance. By determining the Nordell number

of a sewage-sludge mixture and plotting a curve, Nordell was able to devise a formula, from which the condition of the mixture could be calculated for any interval of time and also the time necessary for complete treatment. Computed and determined Nordell numbers at a number of plants show close agreement.

Nordell's experiences led him to the invention of the "Odeeometer" (35), a mechanical device for the direct measurement of oxygen absorption rates. With this device a large sample of four liters of the sewage to be tested is placed in a drum connected to an air chamber. The sewage is stirred and mixed with air by means of a paddle wheel driven by an electric motor, and the direct rate of reduction in air volume is measured. A tank containing caustic soda solution absorbs the CO_2 liberted. The use of Kessler and Nichol's technique and the Odeeometer should open up quite a field for the study of plant behavior.

The method is of interest in connection with the studies made on oxygen absorption by Parsons, Kessener, Scouller, and others. Burtle and Buswell (36) using the Nordell apparatus in a comparative study of permanganate oxygen demand, B.O.D. and direct oxygen absorption, believe that the method has advantages in the determination of B.O.D. over the dilution method, and appears to be less artificial than Sierp's direct oxidation method. They also show, as similar comparisons have always shown, that there is no fixed relation of even approximate usefulness between the permanganate oxygen consumed value and the B.O.D. of various types of waste or even of different sewages.

A rapid colorimetric method for the determination of dissolved oxygen, which can be used in the field, was developed by Isaacs (37). This simple colorimetric method employs amidol and potassium citrate, is carried out in test tubes and comparison is made with permanent standards.

A method to measure odor concentration was described by Fair and Moore (38), formulae were presented to record the intensity of the odors and examples were given for different types of sewages, sludges, etc.

Eldridge (29) has reported an experimental study of the effect of ignition temperatures in the determination of total and fixed residues in sewage analysis. A review by Streeter summarizes the following conclusions:

"(1) No temperature of ignition will give results exactly representing the organic content of sewage and sewage sludge; (2) a temperature around 600° C. for 1 hour for sewage and 2 hours for sludge gives results most nearly representative of the true organic content; (3) a significant loss due to carbonate decomposition occurs with temperatures above 500° C. This loss is more significant with sewage solids than with sludge because of the higher carbonate content of the former."

Pathogenic Organisms.—There are comparatively few papers dealing with the survival of pathogenic organisms in sewage before and after treatment. Most of the studies made deal with specific condi-

tions in water stored in bottles. The difficulties of obtaining results are enhanced by the absence of proper methods for determinations of the pathogenic bacteria in the presence of large numbers of other organisms. Heukelekian and Schulhoff (39), studying the survival of *B. typhosus* in surface waters and sewage, concluded that the rate of decrease in polluted water and sewage is comparatively rapid. The rate of decrease is materially affected by temperature. An actual multiplication may take place with favorable temperatures and in the presence of food supply, feces, urine, and sewage.

In polluted water the survival time is shorter than in clean water. Aeration reduces the survival time, but when present in activated sludge the numbers increase initially (4–6 hours), followed by a rapid decrease. A rapid reduction takes place during anaerobic sludge digestion. With partial chlorination (25 per cent of the demand) over 99 per cent were killed in 10 minutes. The importance of typhoid bacteriophages in a tropical river was studied by Schuurman (40). He found on the basis of laboratory experiments that typhoid bacilli could multiply in river water, but that the influence of other factors generally prevented multiplication, and that the phage increased rapidly in river water, even if no typhoid bacilli were present. In the self-purification processes of river water the phage plays a role not only in restricting the typhoid bacilli, but also in the maintenance of a biological equilibrium.

In this connection the excellent report of Ruchhoft (71) which was inadvertently omitted from last year's review, should be mentioned. He concluded that "Wet activated sludge cannot be considered innocuous." In activated sludge stored at 68° to 72° F. the destruction of viable typhoid organisms was of the order of 99 per cent or better in each 5-day interval of storage. At 50° to 60° F. the corresponding figure was about 90 per cent in 10 days. The author used a convenient measuring rod by comparing throughout the relative viability of *E. coli* and *B. typhosus*. An excellent bibliography was appended.

Activated Sludge

Extent of Process.—Langdon Pearse (41) in his "General Review of Sewage Disposal in the United States," calls attention to the fact that in 1934 there was more capacity under construction or contemplated for the activated sludge process than for any other. He also says "With much of the present interest in sewage treatment focussed on chemical precipitation, it is of more than passing interest to note that Providence, R. I., turned to activated sludge when their plant was remodeled."

Imhoff (42) says "The activated sludge process has been established as the best biological type of treatment for large cities, especially since it has been demonstrated that the excess activated sludge can be digested along with the preliminary settled sludge in heated digestion tanks."

In a survey conducted by *Engineering News-Record* during 1934, and published in August 1935 (43), 44 states reported 104 activated sludge plants, of which 56 were the diffused air type, 35 mechanical, and 13 not indicating as to type of aeration.

It is interesting to note the growth of the process. In 1929, twelve states reported a total of 35 activated sludge plants. These same twelve states five years later (1934) reported 85 plants.

It is also noteworthy that the first plant constructed in United States, at San Marcos, Texas (44), in 1916, is still in operation.

Chicago (45) turned to the activated sludge process for its new 400 m.g.d. Southwest plant.

Design and Construction of Plants.—Pearse (41), points out some of the later design features in economical construction of activated sludge plants, such as "The use of wider aeration channels up to 34 feet, the reduction in the number of water bearing walls in the aeration batteries, and the use of tank bottoms as footings for longitudinal walls; the use of coarser diffuser plates than heretofore with a reduction in the number of rows of plates; and the use of air lifts for control of sludge from the final settling tank and its return to the incoming sewage."

Greeley (46) also mentions these trends. Eddy (47) calls attention to the interference of grease and oil on the activated sludge process, and recommends further study of grease removal devices, and Hyde (48) also recommends grease removal, particularly where the activated sludge process is employed.

Automatic sludge return by twin ejectors was used by Gavett (49) in his plant at Bernardsville, N. J.

Piatt (50) at Durham, N. C., used a new principle in his design of the aeration tanks, in that the plate units, instead of being laid flat on the bottom, were laid lengthwise with plates in a vertical position, to prevent clogging and facilitate cleaning. It would be interesting to observe whether or not all the air will tend to leave the plates at the top, due to difference in hydrostatic resistance. If so, the effectiveness of the plate area would be considerably reduced. This plant was designed to produce all the power necessary for operation from utilization of digester gases. It is possible to isolate one primary settling tank, one aeration tank, and one final settling tank from the rest of the plant to conduct experimental studies.

Leiner (51) proposes to divide the aeration tanks into two groups, "conditioning group" and "overloading group," each followed by a settling tank. In the conditioning group only enough raw sewage is added to keep the sludge healthy and active, and the remainder of the raw sewage flows to the overloading tank.

Settled sludge from the first or conditioning tank is returned to both the conditioning and overloading tanks, while sludge from the overloading tank is wasted. Experience indicates that about 80 per cent purification can be obtained in the overloading tank with about one hour's aeration, as against the conventional 4 to 8 hours in the ordinary

activated sludge plant. With the flow of sewage equally divided between the conditioning tanks, with complete purification, and the overloading tanks of about 80 per cent purification, the combined effluent is as good as that from a sprinkling filter (90 per cent purification). Advantage lies in the saving of tank space and flexibility of operation.

Activated Sludge and Industrial Wastes.—According to Rudolfs (52) tannery wastes have interfered with the activated sludge process at Milwaukee, so that preliminary treatment is required before discharge to the city sewers. In the Niers district (Germany) interfering tannery wastes were treated with a small amount of carbon dioxide gas in the presence of iron filings and then aerated.

Hays at Waco, Texas, and Henderlite at Gastonia, N. C., have reported interference in the activated sludge process from dye wastes. Henderlite added ferric chloride to the raw sewage entering the aeration tanks and was able to produce a practically colorless effluent, with improvement in the sludge.

Large amounts of wool scouring wastes are sources of trouble due to quantities of grease settling out. Boil-off liquor from rayon wastes was successfully treated by the activated sludge process when not more than 6 per cent was present in the sewage.

Treatment of beet sugar plant wastes by the activated sludge process may be made to yield a high degree of purification, although the percolating filter seems most suitable for this waste. Slaughter house wastes can be successfully treated by activated sludge but they require long periods of aeration and large amounts of air.

Sulphides in sewage exert a detrimental influence on biological treatment, either by sprinkling filter or activated sludge. Experience at Fort Worth with oil refinery washings containing large quantities of mercaptans and other sulphur compounds confirms this conclusion.

Nolte, Meyer and Fromke (53) at Magdeburg, Germany, experimented with a small plant having a capacity of 18½ gallons. They report that sugar wastes could be completely purified by the activated sludge process if first treated by the Nolte fermentation process. With 24 hours aeration, 1000 p.p.m. organic acids could be completely destroyed. Using organic materials such as acetic acid, molasses, butyric acid, lactic acid and other organic compounds added to tap water they were able to produce an artificial activated sludge (without the addition of raw sewage), which was quite effective.

The success of this type of treatment appears to depend upon the presence of sufficient amounts of phosphates and ammonium salts for the nutrition of the bacteria, usually secured by the addition of ammonium phosphate. Nolte *et al.* were able to secure almost quantitative decomposition of M-cresol by this process.

Eldridge (29) studied the effect of milk wastes on activated sludge treatment and reported that the high fat content apparently was the cause of sludge bulking.

Effect of Addition of Chemicals to Activated Sludge Process.—

Rudolfs and Chamberlain (54) (55) (56) studied the effect of chlorination on the activated sludge process.

When mixtures of sewage and activated sludge, and activated sludge alone were chlorinated until residual chlorine was present the supernatant or clarified effluent showed increased turbidity and increased B.O.D., which would indicate an inferior effluent from a plant employing chlorination, although the sludge itself showed a reduced B.O.D. and the sludge mixture filtered and de-watered more rapidly than the unchlorinated.

When chlorinating to only partial satisfaction of the chlorine demand of either the sewage or the activated sludge the results again showed increased turbidity and higher B.O.D. in the clarified effluent; the effect apparently being proportional to the amount of chlorine added.

In studying the effect of split chlorination *i.e.* "chlorine added in the same quantities (on the basis of chlorine demand of the sewages) to the sewage, sludge, or in split dose, produced poorer effluents than the non-chlorinated materials." "From the results secured it appears that neither split chlorination of the sewage or sludge was beneficial to the purification process, and that staleness of sludges could not be readily counteracted by chlorination." The settling rate of well-oxidized sludges seems to be somewhat retarded by chlorine.

At Singapore, in experiments using chlorine with a bio-aeration tank it was found (according to Mendelsohn, 57) that chlorine added at rates varying up to 36 p.p.m. to the sewage entering the aeration tank adversely affected biological life in the sludge, although Bell (58) at Barnsley, England, in 1930 reported excellent results when adding chlorine in the form of bleaching powder to the sludge returned to the bio-aeration tanks.

At Lima, Ohio (59), Smith was able to control bulking by adding chlorine to the return activated sludge, in such quantities that the ratio of per cent solids in the sludge to the p.p.m. chlorine applied was kept above 1.00.

The first reports on the use of activated carbon in an activated sludge plant are from Smith at Newark N. Y. (60). The carbon in the form of "Nuchar" was applied to the raw sewage to reduce odors. He reported that the carbon reduced H_2S odors in the raw sewage and reduced scum formation in the primary settling tanks. Some of the carbon carried through to the aeration tanks. The returned sludge was blacker in color but no change was noticed in the dissolved oxygen content of the final effluent. There was no noticeable effect on the daily gas production, although later (61) he reports that the gas production was increased.

Sartorius (62) reports that large amounts of carbon have a destructive action on the bacteria.

Rudolfs and Trubnick (63) studied the effect of activated carbon on the activated sludge process and report that there was no effect on the turbidity or oxygen consumed values of the effluent when so treated. A very slight difference in the compacting of the sludge was noticed.

Goudey (64) claims to have improved the activated sludge process by raising the pH value of the raw sewage to 6.5 by addition of lime. Raw sewages with pH values below 6.5 are not commonly encountered unless they have been altered by some form of pre-treatment or contain trade wastes. It would be interesting to observe the effect of raising the pH to the optimum values for the growth of *Zooglea ramigera,* the coagulating organism isolated by Butterfield. Goudey also recommends that lime, a ferric salt, and copper sulphate should be added to control the pH and prevent excessive bacterial growth.

The addition of ferric salts by Henderlite has previously been mentioned. Nesmeyanov (65) added various iron and aluminum compounds to activated sludge. The addition of $FeCl_3$ or $Fe_2(SO_4)_3$ in amounts of 0.0087 to 0.5 gram Fe per liter of sludge-sewage mixture produced a retarding effect on the oxidation, particularily on the nitrogen compounds. Aluminum salts gave similar results.

The action was not attributed to the iron or aluminum but to the change in acidity resulting from hydrolysis. Nesmeyanov also states that the small amount of iron necessary for the growth of the bacteria is normally always present in the sewage.

Plant Operation.—A Chicago combination aerator and clarifier at Monroe, Wis., has been reported upon by Kessler and Morgan (66).

This unit treats domestic sewage containing quantities of milk wastes, at rates varying from about 29,000 to 115,000 gallons per day. The sewage has a B.O.D. from 180 to 594 and suspended solids from 94 to 170 p.p.m. The effluent ranged from 13 to 122 p.p.m. B.O.D. and suspended solids 12 to 57 p.p.m., with aeration periods ranging from 28.3 hours to 7.1 hours. Current for aeration was from 782 to 3900 K.W.H. per million gallons.

In last year's report of the Research Committee (67) mention was made of the construction of a 16 m.g.d. diffused air plant, a 1 m.g.d. Simplex plant and a 0.6 m.g.d. bioaeration plant at the Davyhulme Plant, Manchester, England. Results of operation of these plants have been published (68) and abstracted by Hoskins (69).

These results are shown below.

	Diffused Air		Simplex	Bio-Aeration
	High Supply	Low Supply		
Per cent reduction biochemical oxygen demand	92.5	89.2	93.6	84.9
Per cent reduction albuminoid nitrogen	73.6	62.3	76.0	61.8
Per cent reduction oxygen demand at 26.7° C	73.5	68.7	75.2	66.8
Sludge return per cent			9–12	5–8
B.H.P. required per mil. gals	36.95	30.55	26.9	40.7
Cubic feet air per gallon	1.200	0.887		
Detention period—hours	12.1	12.7	14.6	16.3

It will be seen that these results are decidedly favorable to the Simplex process.

Bulking of sludge at Newark, N. Y. (70), was corrected by wasting sludge until the solids in the mixed liquor fell to 2500 p.p.m., while at Lima, Ohio, Smith obtained the desired results by the use of chlorine (previously mentioned). He was able to correlate bulking with the presence of large amounts of filamentous organisms, and when bulking was controlled by chlorination the organisms were present in very small quantity or absent.

Research and Experiments.—During the past year a number of papers have appeared describing investigations on the theory and mechanism of the activated sludge process. Edwards (72) has presented an important review of the various theories that have been proposed and Theriault's work has been referred to in the Biology and Chemistry section. In this connection Mohlman's (73) editorial is quite pertinent, wherein he states "a complete theory is bound to be quite complex, including as it must the relation of surfaces, bacteria, protozoa, oxygen content, temperature and time." He further calls attention to the dual factors of environment and the actual mechanism of the reaction, and need for their correlation.

Perhaps if one were attempting to form a general quantitative idea of the relative importance of the purely physico-chemical phase, against that of the biological, an analogy might be drawn between chemical precipitation methods and the activated sludge process. The purification affected by chemical precipitation might be considered as approaching a measurement of the physico-chemical phase while the remaining purification effected by complete activated sludge treatment might be considered truly biological.

Regardless of which theory one may accept, a certain fundamental requirement is paramount, that of oxygen demand satisfaction. This oxygen must be supplied to the sludge and/or mixed liquor as fast as it is utilized.

In a paper read at the annual Summer Conference of the Association of Managers of Sewage Plants, at Glasgow July 1926 Harris, Cockburn and Anderson (74) point out that .0586 cu. ft. of air is required per gallon of sludge, per hour which is equivalent to about 109 mg. of oxygen per liter. Theriault and McNamee (75) reported a demand of 89 mg. while Grant, Hurwitz and Mohlman (76) reported 150 mg. per liter for the first hour.

A number of research papers on the process have been produced at the New Jersey Experimental Station under the direction of Dr. Rudolfs.

Heukelekian (77) studied the biochemical changes taking place in sewage and sludge when treated by the activated sludge process. He summarizes, "The two main processes involved are flocculation and oxidation. Aeration enhances flocculation by transferring the sewage solids into the sludge floc. Over-aeration causes a redispersion of the

flocculated solids. Simultaneous with the flocculation, oxidation of the solids in the dispersed as well as in the floccular form is taking place."

Sludge having the greatest purifying capacity was obtained by 4 to 7 days aeration, when using the B.O.D. as a criterion. Judged by nitrate formation, the optimum occurred on the seventh day. There was a definite loss in suspended solids due to aeration.

Continuing the experiments, Heukelekian made observations on the effect of varying the daily charge of solids added (78).

If the daily addition of fresh suspended solids was equal to the withdrawal of suspended solids in the sludge, the concentration could not be maintained since there was a loss of suspended solids during aeration. With low charges of solids the losses were high, and with high charges the losses were low. The character of the sludge and degree of purification were also affected by the daily charge. If the charges were too low an over-oxidized sludge was produced, indicated by the high ash content and low B.O.D. suspended solids ratio and higher turbidity of the effluent. If the charges were too high, the sludge had low ash content, high B.O.D. suspended solids ratio, and high suspended solids in the effluent. The optimum quantity was somewhere between 3.4 and 17.7 per cent.

Heukelekian (79) also studied the effect of aeration on the removals of suspended solids and B.O.D. in the absence of activated sludge. He concluded "It was found that with different sewages an aeration period of 6 hours followed by sedimentation resulted in a greater degree of purification than could be obtained by plain sedimentation, based on suspended solids and B.O.D. determinations. The higher removals were brought about not by oxidation but by the flocculating effect of the sludge." This has also been confirmed in studies by the British Water Pollution Research Board (80), where no appreciable difference was noted when bubbling air, oxygen, hydrogen or nitrogen through the sewage mixtures. Settled solids should not be returned for the purpose of increasing the removals since the effluent will be of poorer quality.

Ridenour (81) continued his studies on the effect of low solids concentration in activated sludge, and reported that suspended solids as low as 150 p.p.m. could be carried and still the sludge could be maintained in activated condition. Ridenour states that settling of activated sludge is a two-stage process, the first of which is flocculation of suspended solids, then followed by normal settling.

Buswell and Long have reported some years ago that activated sludge floc is characterized by large numbers of filamentous bacteria and occasional *Zooglea ramigera.*

Hatfield and Agersborg, at Decatur, Ill., found that the sludge in their pre-aeration tanks consisted almost entirely of *Zooglea ramigera* and *Sphaerotilus.* Since the action of these tanks is primarily one of colloid coagulation it would appear that these organisms are of prime importance.

Setter, Ridenour and Henderson (82) point out that numerous

authors ascribe the mechanism of coagulation to the colloidal properties of the sludge. They have attempted to show that variations in the colloidal properties of the sludge are reflected in the composition and character of the floc. In order to evaluate these properties they measure the "cation exchange capacity" of the sludge by means of the barium acetate-ammonium chloride method for soils. With this procedure they were able to show that an increase in the cation exchange capacity corresponded with an increase in the settling characteristics of the sludge.

While the plain aeration of sewage is not to be confused with the activated sludge process, the results of this treatment are too significant to be omitted, especially as an adjunct to other treatments. Heukelekian (79) has reported his results, based on laboratory findings. Attention should be called to Nauta's (83) experiments, wherein he found that strong Amsterdam sewage, with a 3½ hour period of aeration, could be handled on sprinkling filters at 7 to 8 times the normal rate.

Experiments at Singapore (57) indicated that pre-aeration increased the capacity of a sprinkling filter about four-fold.

Sludge Handling and Disposal

Digestion.—Separate sludge digestion, with special reference to digestion temperatures and to gas production and utilization, continues to receive a considerable part of the attention of the sewage works investigators. Walraven (84) has utilized for experimental purposes the facilities of the Springfield, Illinois, plant, in which an average flow of 7 m.g.d., with no material quantities of industrial wastes, is treated in primary settling tanks followed by the activated sludge process. His report is an excellent example of what may be done in the way of accumulating data of research value by the careful observation of a plant under routine operating conditions. A series of tests on the coefficient of heat interchange from submerged heating coils gave a value of 11 B.T.U. per sq. ft. of heating surface per hour per 1° F. differential, with a sludge of 12 per cent solids, and a corresponding value of 39 B.T.U. with a more dilute sludge approximating strong supernatant liquor. Detailed analytical data are given, which show the composition and total output of sludge by months, with corresponding tank temperatures. The yearly values are likewise compared with those of the three previous years.

In view of the interest which has been aroused by Cohn's advocacy of household garbage grinders discharging into the house sewer, Babbitt (85) has considered the implications of this proposal from the point of view of the sewage works operator. On the basis of existing data he arrives at the conclusion that with a general introduction of this method of garbage disposal, the solids of domestic sewage will be about doubled and the nature of the garbage material makes it somewhat more difficult to digest. Babbitt claims that B.O.D. will be increased

about 25 per cent and difficulties arising from the presence of grease will be largely aggravated, both as to quantity and character of the grease.

The introduction of the crude garbage equivalent to the contribution of 100 persons into an experimental Imhoff tank having a capacity of about 250 persons gave highly unsatisfactory results. While the author ventures no final judgment upon the question, he anticipates serious trouble in any digestion system called upon without redesigning to handle a heavy load of garbage. He believes however that research will provide the solution to this situation.

Agricultural Use of Sewage Sludges.—DeTurk (86) briefly reviews the historical picture and then presents a discussion of fertilizer value based upon chemical composition and field experiments, written entirely from the point of view of the Agricultural Experiment Station, which, it may be noted in passing, is distinctly different and possibly a more detached point of view than that of the sewage works operator. Digestion of the sludge not only reduces its total nitrogen content but also reduces the "availability," in the agricultural sense, of the nitrogen which remains. Experimental results indicate that the effectiveness of this nitrogen is about one-fourth that of nitrogen in nitrate of soda and one-half that of the nitrogen in cottonseed meal. Activated sludge on the other hand not only has a higher total nitrogen content but the effectiveness of the nitrogen is roughly double that of digested sludge. The latter is roughly equivalent to farm manure, both on a chemical and on a utilization basis. There is also a brief discussion of the utilization of the sludge as a basis for the preparation of a more concentrated commercial fertilizer.

Among the various complications which surround the problem of the satisfactory utilization of sewage sludges in agriculture an occasional reference to the sanitary and public health significance of such practice comes to our attention. This situation has been discussed by Tanner (87) in a brief but satisfactory manner, with an excellent list of references. Discussing first the probable longevity of the typhoid organisms in soils he concludes that, under ordinary conditions in sewage polluted soil, survival for as long as 74 days must be anticipated. The presence of nutritive material seems not to be a determining factor. The organism may be carried by drainage through a considerable layer of finely packed soil, and may be transported in a viable condition from dried soil and sand by wind or air currents. He advises caution in the use of sewage sludge in connection with truck gardening. In this connection the studies of Heukelekian and Schulhoff referred to in the section on "Chemistry and Biology" and indicating a comparatively rapid death rate of the typhoid organism during sludge digestion are somewhat comforting.

Genter (88) has reported results of further work on sludge elutriation, using formalin, chlorine, or hypochlorite in addition to elutriation with water. The resistance of sewage sludges to coagulation is caused by soluble products of decomposition, notably the amino-ammonia

nitrogen. Genter shows that the amount of coagulant required is almost directly proportional to the amino-ammonia nitrogen content of the liquid sludge. Sludges containing 100 p.p.m. of amino-ammonia nitrogen required 2.2 per cent of ferric chloride, while those containing 325 p.p.m. required 8 per cent to give maximum filter rates. When the 325 p.p.m. was reduced to 15 p.p.m. only 1 per cent ferric chloride was needed to effect the same result.

Sludge Dewatering.—Keefer (89) at Baltimore has continued his valuable investigation of sludge dewatering, with special reference to the advantages of elutriation as a preliminary to vacuum filtration. He presents data of his large scale experiments, including costs, which are compared with the costs of the older process of sludge drying on sand beds. On a dry solids basis, the most economical procedure, using chlorinated copperas with elutriation, involves a total cost of $3.28 per ton of dry solids. This is compared with a cost of $4.38 without elutriation and approximately $6.13 by air drying.

Spray Drying of Sludge.—Cost estimates have been presented by Downes (90) on the results of the spray drying of sludge at Plainfield, Handling all the digested sludge from a population of 50,000, it is necessary to operate 9 hours a day, 6 days a week. Digested sludge of 5 per cent solids is concentrated by flotation with alum (4 lbs. per ton of sludge), and is atomized by a spray type drying bowl 6 inches in diameter turning at 9600 r.p.m. and delivering sludge at the top of the drying tower. Drying at 70 lbs. per minute the sludge resembles a good loam fertilizer, but has about 30 per cent moisture. Under Plainfield conditions the cost is estimated at $9.86 to $12.04 per ton of dry solids. It is stated that the product can be sold at $10.00 per ton (equivalent to $12.04 per ton of dry solids) or it may be burned by blowing it back over the fire. Drying digested sludge gives off no offensive odors, but raw sludge cannot be successfully dried without odor under present operating conditions.

Chemical Treatment

The outstanding publication of the year in the field of chemical treatment is the report of a committee of the Public Health Engineering Section, American Public Health Association, under the Chairmanship of Langdon Pearse, which most fortunately has been printed in full (91), despite its length of 108 pages. We mention this report for the sake of completeness since its availability and character make unnecessary any attempt to digest it. Dr. Mohlman's editorial comments on this report in the same number of the *Journal* should also be read.

A paper by Blew (92) admirably complements the Committee Report in that it presents a somewhat more expanded historical survey of the use of chemical processes. The author reminds us of the interesting fact that the conclusions of Hazen to be found in the Report of the Massachusetts State Board of Health for 1890 represent quite ac-

curately our present day knowledge as to the relative merits of various chemical precipitants. (See also items on chemical research under "Chemistry and Biology" and under "Chlorination.")

Activated Carbon.—The use of activated carbon in the various stages of sewage treatment seems to be attracting increasing interest. Rudolfs and Trubnick (63) present a useful discussion of the manufacture of activated carbon and of some of the principles and theories of adsorption which have been proposed.

Their own experiments deal with the effective adsorption of CO_2 and other volatile acids, to which effect they ascribe the rise in pH generally noted when activated carbon is added to sewage. The relation between concentration of acid, concentration of carbon and time of contact both with CO_2 and with butyric acid were studied in detail.

No evidence was obtained of any improvement in flocculation or in net purification of raw sewage treated with varying concentrations of activated carbon and later gently flocculated and settled for one-half or one hour, nor was there any improvement in the B.O.D. or oxygen consumed values. Similar negative results were obtained in conjunction with partial coagulation with iron salts.

With more nearly complete flocculation with ferric chloride there was some improvement in settleability using carbon dosages from 5 to 25 p.p.m. and progressive improvement after filtration of the treated sewage up to 10 p.p.m. of carbon.

Activated carbon was found to have a deleterious effect upon chlorine disinfection which, although irregular, the authors consider to be significant and which they ascribe to the direct adsorption of chlorine. In connection with activated sludge no improvement in the settleability or in the resulting turbidity and oxygen consumed was noted with dosages of carbon up to 40 p.p.m. Digestion of fresh solids is apparently accelerated. Six and a half p.p.m. of carbon reduced the digestion time by one-half and 13 p.p.m., by about two-thirds or from 127 to 42 days. Gas production was likewise stimulated but to no greater extent in the case of the increased carbon dosage.

Rogers (93) likewise noted, at Garden City, New York, that addition of approximately 5 p.p.m. of activated carbon to the sludge introduced into separate digestion tanks, which are unheated, brought about an increased rate of digestion, although in the absence of a control tank his judgment is based merely upon past performance of the tank in question under similar weather conditions.

Rudolfs and Trubnick observed that activated carbon seemed to be without particular benefit when applied to a trickling filter effluent and that while it tended to reduce the odor of stale sewage the effect was probably one of hydrogen sulphide adsorption. In laboratory tests they found that the presence of carbon actually accelerated hydrogen sulphide formation.

Field investigations were likewise carried out at Princeton, New Jersey, and at East Rochester, New York, in which the effect of the carbon upon digestion was confirmed and in addition a material im-

provement was noted in the matter of scum formation and separation of sludge and liquor in the digestion tank.

Mechanical Equipment

A brief paper by Agar (94) summarizes the advances that have been made in the use of mechanical equipment in sewage treatment during the past few years. For purposes of classification he defines mechanical equipment "As any device with moving parts which performs or assists in carrying out any of the necessary steps in a treatment process." While this definition logically includes pumps, this item is omitted from the definition in deference to custom. The author refers to the adoption of a total of 54 pieces of mechanical equipment, including 23 mechanically operated settling tanks, among the 33 sets of plans submitted to the New York State Dept. of Health during the past two or three years.

The performance of a Laughlin magnetite filter preceded by sedimentation of various periods, and compared with the results of sedimentation alone, has been reported by Rudolfs, Brendlen and Carpenter (95) on the basis of experiments made at Coney Island, New York. The sewage experimented with had average values of 143 p.p.m. B.O.D. and 105 p.p.m. suspended solids. The settleable solids averaged about 53 per cent of the total suspended solids.

The experiments were on plant-size scale and individual tests were carried out for from 70 to 187 hours each. Plain sedimentation for periods of from 1 to 2.3 hours resulted in removals ranging from 27 to 58 per cent of suspended solids. Subsequent filtration resulted in an additional removal of about 25 per cent of the initial value and this was largely independent of the rate of filtration where the rates varied between .58 and 3.31 gals. per sq. ft. per min. Results on the removal of turbidity and B.O.D were of similar character. One hour's sedimentation followed by filtration at the maximum rate gave results superior to those of a 2-hour period of sedimentation without filtration. The authors comment upon this result and upon the flexibility which is thereby introduced into the system.

A similar study, except that it deals with the treatment of the final activated sludge settling tank effluent, is reported by Zack (96). The purpose of this study, which was carried out at the North Side Sewage Treatment Works of the Sanitary District of Chicago, was to determine (1) the applicability of the Laughlin filter to this particular type of effluent and (2) the quality of final effluent obtainable at various settling and filtering rates. Rates of filtration in the 10 separate series of tests ranged from 1.65 to 4.2 gals. per sq. ft. per min. The various analytical data are reported upon in detail. It is concluded that the magnetite filter is mechanically adapted to this particular work, that effluents of some 4 to 5 p.p.m. suspended solids and about the same concentrations of B.O.D. are uniformly attainable with standard rates of settling and filter rates of 2 gals. per sq. ft. per min. Higher rates of filtration

were evidently effective but were limited by capacity for sludge concentration.

In a series of articles Streander and Blew (97) describe mechanical equipment for handling coagulant and sludge and review recent improvements in coagulation control. The author's conclusions may be briefly summarized as follows: The removal of the colloidal portion of sewage solids, since they may carry either a positive or a negative charge, depends largely upon the character of the water supply, therefore each sewage presents a separate problem. Proper coagulation raises or lowers the electric charge to the isoelectric point. Below pH 7.0 ferric chloride is preferable for conditioning sludge. For treating sewage, the iron salts are about equally effective on a ferric iron basis. The cost per unit of iron therefore governs the selection of the iron salt. To smooth out the load and reduce variations in flow, pre-treatment in sedimentation tanks may be used or the same results secured by final filtration. The use of chemical sludge from final tanks is beneficial, but the use of inert substances is of questionable value except for conditioning sludge. Continuous sludge removal is necessary for efficient operation. Two to three hours detention should be provided, or if the effluent is filtered, one to two hours. Filtration will generally produce a saving in chemicals and it will permit the use of smaller sedimentation tanks. A filter rate of 2 to 4 gals. per sq. ft. per minute should give 90 per cent removal of suspended solids. Usually ferrous sulphate will produce a sludge containing 2 to 4 per cent of dry solids and ferric chloride a sludge containing 3 to 5 per cent dry solids. When both lime and a ferrous or ferric salt are used, the increase in quantity of dry solids will be from 20 to 40 per cent.

Filtration

It is significant of the trend of the times that *This Journal*—including the Review Section—lists for 1935 only one reference to a sewage filter and this merely to methods of collecting samples. Other "filtration" items refer to mechanical filters. Under this heading, however, we may appropriately refer to a symposium held at Pasadena (98) before the Public Health Engineering Section, A.P.H.A., on sewage farming as practiced in the southwest. Papers by Ehlers of Texas, Roberts of Arizona and Reinke of California deal with the extent of the practice and its economic phases.

Ehlers presents the "suggestions" of the State Board of Health of Texas, including prohibition of sewage farming in connection with vegetables eaten raw. In Arizona fodder crops and cotton only are grown. Since 1933, California's regulations have been based upon classification of effluents rather than of crops. Raw sewage and undigested sludge are prohibited. No restrictions are placed upon the use of well oxidized and disinfected effluents, while settled effluents, not disinfected, may be used on nursery and fodder crops, cotton and sugar beets, but not on vegetables, berries or low growing fruits. Sewage farming is sewage disposal from the administrative point of view.

Chlorination and Allied Processes

Chlorine application, and the use of chlorine as an integral part of chemical methods, has continued to develop a field of increasing scope in sewage treatment. Pre-chlorination to prevent odors and concrete disintegration; post-chlorination for the disinfection of sewage, oxygen demand reduction, and the maintenance of stream quality—these appear to be such well-established functions as to be included wherever chlorination can serve such a purpose.

Chlorine and Sludge Bulking.—In a valuable series of laboratory studies Rudolfs (99) and co-workers report the effect of chlorination on activated sludge. They substantiate the opinion that activated sludge requires a balanced flora and fauna for a maximum degree of purification and stabilization; that complete chlorination is dangerous since it affects clarification as well as oxidation and stabilization. Like complete chlorination, partial chlorination may be dangerous and treatment of sewage or of activated sludge before mixing produces a poorer effluent. Chlorination of poorly oxidized sludge, bulky or fluffy in nature, while not causing an increase in purification power, did increase settleability. Small amounts of chlorine may be beneficial where poor, bulky sludges, difficult to concentrate are encountered.

E. E. Smith (100) reports the results of his experience at Lima, Ohio, with chlorination of returned activated sludge for the control of bulking. During the summer of 1934 a marked increase in filamentous fungi in the aeration units seemed to be correlated with poor settling of sludge in the final settling tanks. All the usual remedies were tried unsuccessfully, but chlorination of the returned sludge, using only a low dose of chlorine, entirely eliminated the difficulty.

Microscopic examination of organisms and hourly determination of settleable solids in the aeration tanks formed the basis of chlorine addition. With a ratio of less than 1 p.p.m. chlorine for each per cent solids in the returned sludge, bulking condition could be prevented. For example, with a suspended solids content of 1.94 per cent in returned sludge (1.105 m.g. day rate), only 9 pounds of chlorine, ratio 0.5, proved adequate to prevent bulking. Treatment enabled the reduction of air to little more than the delivery of the smallest sized blower, which was a new experience at this plant.

Chemical Treatment Prior to Activated Sludge.—Calvert (101) has made comprehensive laboratory and semi-plant scale experiments (2 to 3 m.g.d. rates) using ferrous sulphate and ferric chloride. Iron was easily available from a galvanizing plant waste. Experiments showed a marked improvement in both activated sludge and sludge settling, but the cost was excessive. Ferrous sulphate added at a rate of 166 lbs. per m.g. enabled handling 39 per cent more sewage than was handled in the control experiment, with approximately the same B.O.D. reduction. When ferric chloride was added to the return sludge, at 479 lbs. per m.g., 23 per cent more sewage could be treated, producing a sludge settling in one hour and containing about twice the concen-

tration of dry solids as in the untreated. The B.O.D. of the effluent was not improved.

Laboratory experiment gave as the best cost figure 2.8 lbs. B.O.D. removed per lb. ferric chloride. This would make B.O.D. removal cost $14.00 per 100 lbs. at existing chemical prices. Cost the preceding year for routine plant operation was $3.43 per 100 lbs. B.O.D. removed. While the plant needs can be met to some extent by chemical treatment, Calvert concludes that the cost of the method investigated is too high for continuous application.

Chlorinated Iron.—While chlorine continues to serve as a useful adjunct in the prevention of odors and the protection of concrete and masonry sewers, the use of ferrous chloride—as produced from the reaction of chlorine water and scrap iron—has distinct advantages. Chlorine consumption is reduced and efficiency is increased. Adequate disinfection takes place and the sulphides react more readily with the iron than with chlorine. Riker has reported (102) on the efficiency of the process at Princeton, N. J., where not only the control of odors but operation of the sprinkling filters and digestion and drying of sludge were aided. Pre-chlorination was used, but never sufficient to overdose the sewage, peak conditions being met by ferrous chloride solution, prepared by the action of chlorine water on crushed tin cans. Odor conditions of previous years did not occur and despite the high B.O.D. and chlorine demand of the raw sewage less chlorine was used. The iron turned the surface of the sprinkling filter brown and continuous unloading was reduced. While the bacterial content of the filter effluent was higher than in 1933, the B.O.D. was reduced, indicating more effective oxidation in the filter with less bactericidal effect. At this plant it is necessary to be particular about odors and the margin between sulphide and chlorinous odors when pre-chlorination alone was used, was so narrow that the latter were often in evidence.

At Oklahoma City, Scott (103) reports on the effect of iron chloride when the sewage reaches the plant in a septic condition. Some eight miles of flow from the city, low grades, and high temperature contribute to this condition. The hydrogen sulphide reacted immediately with the iron chloride to form ferrous sulphide and this served to eliminate trouble from odors produced by packing house sewage. Previously, the attack on concrete had resulted in the collapse of several sewers, necessitating expensive repairs. Chlorine alone was required in excessive amounts to react with the hydrogen sulphide, as large quantities were first taken up by the organic matter in the waste. When added as iron chloride none reacted with the organic matter and all was available to react with the hydrogen sulphide.

Details of operating results and costs have become available from plants using the Scott-Darcy method of producing iron chloride from scrap iron and tin cans (104). Scott reports on three years of experimental work at Oklahoma City and considers the last three months of complete operation. For this period the cost of chemicals used aver-

aged $4.08 per m.g. Treatment, including wages, salaries, power, maintenance, and overhead has been $8.04 per m.g. treated. The effluent produced is clear and the condition of the creek satisfactory, as there are no unsightly solids and no odors. Sludge pumped from the clarifiers averages 10 per cent solids and is dewatered on a vacuum filter at a rate of 5.5 lbs. dry solids per sq. ft. per hour. Average moisture of the cake is 62 per cent. Sludge is stable and gives no odors even though later wet by rain. The equipment of the plant is mostly automatic and is all under the supervision of one operator.

Scott found that iron chloride solutions could be made with different characteristics and different coagulating qualities dependent upon different amounts of iron in solution. By controlling the rate through the chlorinating tower and the strength of the chlorine solution, it was possible to make an iron chloride solution containing large quantities of colloidal iron. This was found to be the best coagulant. Before precipitation the pH of the sewage is adjusted at this plant to 8.5 by the use of lime.

At York, Nebraska, Veatch reports (105) that iron chloride made from tin cans and chlorine, used for coagulation, at the rate of 120 lbs. per m.g. with hydrated lime at 180 lbs. per m.g., gives a B.O.D. reduction up to 75 per cent. Suspended solids of the sewage varied from 364 to 192 p.p.m. in the raw sewage and from 100 to 28 in the effluent. With chlorine at 10c per pound, the chemical cost is $5.50 per m.g. and total cost of treatment $15.08 per m.g. Veatch reports no interference with digestion of the chemical sludge. Chemicals are added only during eight hours daily, as gaugings show 70 per cent of the flow is during this period. Return chemical sludge is used to increase efficiency.

Tests With Chlorinated Iron Coagulants.—At Dallas, Texas, Steel and Zeller (106) made a study of the chemicals commonly used in precipitation methods. Over the pH range of 2 to 12, they found ferric chloride in general gave the best results with pH on the acid side, considering minimum dosage and chemical cost. In a miniature plant treating .23 m.g. per day using chlorine and iron filings as a source of iron coagulant, a removal of 77 per cent of the B.O.D. (originally 350 p.p.m.) and 86 per cent of the suspended solids was obtained. The chemicals required were 1500 lb. chlorine and 200 to 400 lb. iron turnings per m.g. The effluent was clear and the process odorless, but the cost was $25.00 to $50.00 per m.g. It was cheaper to make the iron chloride at this location (iron turnings free; chlorine $.025 per lb.) than to purchase it and laboratory experiments showed a freshly prepared solution of coagulant to be more effective.

Since June, 1935, the modified Guggenheim process has been in operation at a large pilot plant treating the sewage of New Britain, Conn., which contains varying quantities of iron waste. The ability of the plant to utilize the iron-bearing waste as a goodly part of the coagulant (virtually as chlorinated copperas) and to obtain a uniformity of operation points to the flexibility of chemical treatment. Chlorinated copperas is used to maintain a regular dose of coagulant in the

waste and the return of chemical sludge with some aeration produces an effluent of excellent appearance. While no analyses have been reported, engineers employed by the City have recommended the chemical process over the biological process previously considered for the situation.

Hardenbergh reports (107) results on chemical treatment at Liberty, N. Y., to provide partial treatment during the summer months. Three-quarters of a million gallons of sewage with a B.O.D. of 300 to 700 p.p.m. was treated daily. Chemical addition proved most effective at about the one-third point in the mixing tank with a minimum of air agitation following. Though no data as to B.O.D. or suspended solids removal have been made available, good results were reported with chlorinated copperas, ferric sulphate and prechlorination, and Blackalum (alum plus activated carbon). The latter improved the drainability of the sludge.

At Atlanta, Ga. (108), tests over a short period indicated that chemical precipitation with chlorinated copperas permitted loading trickling filters at a 6 m.g.d. rate—three times the rate of parallel filters without iron—giving oxidation even greater than the normally loaded units. The effluent contained much small floc which was readily coagulated in final tanks by a secondary iron dosage. This is in agreement with Downes' work at Plainfield, N. J.

It is shown by Hurley (109) that iron pickling liquors can be admitted to sewage with no harmful effects. Sewage settled 16 hours and sewage containing the proper proportion of pickling liquors were applied to separate filters. A superior effluent was obtained from the filter receiving the latter.

Disinfection.—More evidence has been offered that substantial reduction of bacteria in sewage may be obtained by partial chlorination (less than complete satisfaction of the chlorine demand). The reductions increase with chlorine dose and time of contact. The studies of Rudolfs previously showed that in untreated sewage nitrogenous substances have a large chlorine demand and the bacterial kill was almost instantaneous.

Mallman and Shephard (110) have investigated this phenomenon at the Traverse City, Mich., disposal plant where a settled sewage is chlorinated before discharge to the lake. Employing dosages ranging from 80 to 100 per cent of the initial chlorine demand, and contact periods of 7, 14 and 21 minutes, they find progressive reduction of 37° counts, with time of contact as well as with dosage. Their conclusion that, with partial satisfaction of the demand, the rate of killing falls off with time is not supported by their graph of the data, which indicates a very close agreement with the theoretical constant death rate at each concentration. Another deduction from this graph is that, measuring concentration of dosage in terms of final residual chlorine (or its negative, residual demand), and plotting data against this scale, the rate of killing is a linear function of this concentration term, the relation being continuous from the region of excess residual chlorine

to that of residual demand. The data suggest a uniformity in the basic reactions of chlorine disinfection in which the so-called chlorine demand (a convenient but arbitrary fiction) plays no critical part, acting merely as a neutralizing agent.

Rudolfs and Gehm (111) show that the reduction in total bacteria (20 degree count) and in *B. coli* varies with the contact time employed and types of substances present, but this reduction is followed by great increases after incubation. In all cases, except when 100 per cent of the chlorine demand was satisfied, growth occurred within 6 hours after incubation but no counts reached the original numbers until after 24 hours of incubation. The authors found aftergrowths to be not directly proportional to the quantity of chlorine added. When 50 to 75 per cent of the chlorine demand was satisfied, no protozoa were present after 72 hours of incubation; with a lower chlorine demand the rate of kill was greater, and the per cent reduction varied with the per cent satisfaction of the demand. An important point is that the protozoan numbers are reduced to a greater extent by the germicide, due to their lower initial population and greater sensitivity. The lag period for these organisms is longer than that of bacteria, therefore the bacterial population is allowed to increase unhampered. Chlorine-resistant bacteria may be partially responsible.

Industrial Waste Treatment.—It may frequently happen that industries will be required to give their wastes pre-treatment, if the municipal sewage treatment systems are to be utilized. Chemical treatment seems to be indicated in many cases. At Durham, N. C., three of the larger textile mills have established pre-treatment plants to enable the city's new activated sludge plant to handle the mixed sewage. Chlorine and chlorinated iron are used as flocculants for the textile mill wastes. At Spindale, N. C., where the combined wastes and sewage are to be given chemical treatment, the only restriction on the industrial plants is regulated discharge of the wastes.

Septic tank treatment and lagooning of meat packing waste proved unsuccessful at Grand Rapids, Mich. Eldridge (112), carried out laboratory experiments on chemical precipitation which have been followed by full scale operation of a 5,000 gals. per day plant. The waste has a B.O.D. averaging 2,000 p.p.m. and in view of the small volume with high organic content coagulation with chemicals proves more desirable than biological treatment. Chlorine gave the best results of any coagulant tried, giving reductions averaging 62 per cent of total solids, 78.5 per cent of volatile matter and 92.6 per cent of B.O.D. Supernatant liquor treated with chlorine can be discharged to the stream or returned to the treatment plant. Sludge is collected in a septic tank where it may be stored about three months.

The new Cedar Rapids, Iowa, plant has been reported (113) as being partly in routine operation. Separate pre-treatment of meat packing wastes is necessary. Sulphuric acid is used to adjust the pH of the waste and then ferric chloride is added for coagulation with provision for returning the sludge. Digestion of flocculated and primary sludge

is practiced. Pre-chlorination of the raw sewage is used for odor control. Average B.O.D of the packing waste is 2000 p.p.m. with a maximum of 4000 p.p.m. Chemical costs so far indicated are less than $8.00 per m.g. for the removal of the objectionable material which would affect sprinkling filters. Preliminary results show economical doses of iron will give a 40 to 50 per cent reduction in B.O.D. Digested sludge will be conditioned with ferric chloride and dewatered on vacuum filters.

At Rockford, Mich., Hubbell (114) reports on plain sedimentation of tannery waste and dewatering of sludge. Spent tannery waste containing hide, hair and fleshings, with a B.O.D. of over 600 p.p.m., a pH of 9.0 and a maximum suspended solids content of 12,000 p.p.m., is mixed with sewage. The mixture is settled in two rectangular tanks with mechanical scrapers. Sludge is conditioned with lime, using 6.4 per cent on a dry solids basis, and dewatered on a vacuum filter. The feed averages 94 per cent moisture and the filter cake 70 per cent; a yield of 2.84 lb. of dry solids per sq. ft. per hr. is obtained. The filter yield could be increased by conditioning with ferric chloride, but the cost would be greater than that of operating the filter for the additional time necessary with the lime conditioning alone. The cake is a good soil builder and is readily disposed of on adjoining farm land.

Stream Pollution

Interest in the general subject of stream pollution has continued at the same high level and with the same practical outlook mentioned in the report of last year, in connection with the report of the National Resources Board. An excellent summary of the present status with a suggested outline of a nation-wide system of regulation and control has been presented by Hoskins (115). Opening his paper with quotation of a resolution adopted by the American Association for the Advancement of Science "Urgently recommending the adoption of legislation adequate to control pollution of public waters" Hoskins refers to the necessity for conserving public water supplies, increasing damage suffered by riparian owners, deterioration in recreational and esthetic values, and economic loses suffered by industrial and commercial users. He points out that, in the section north of the Ohio and Potomac and east of the Mississippi, 65 per cent of the total urban population of the country is found in 14 per cent of its total area. The rural population in this section has a density of 40.5 persons per square mile. He estimates that 75 per cent of the urban population is connected to sewers and that equivalent industrial pollution, as determined by various river surveys, ranges anywhere from 85 to 124 per cent of the pollution from domestic sewage. Not more than one-fifth of this total potential pollution load is being reduced by treatment.

After calling attention to the essentials of an adequate program of relief, namely, the acquirement of exact information as to stream conditions and capacity and the establishment of a comprehensive and

equitable control machinery, he deals specifically with the respective responsibilities of federal, state and local administrative groups as at present constituted, with the desirability of interstate regional boards with some central authority, and of a continuing technical group, preferably in the central authority, having research and broad advisory functions.

Recreational Use of Waters.—It was probably inevitable that the rising curve of popular interest in recreational facilities—in which water of some sort is the center of attraction—would eventually meet and cross the decreasing curve of cost of waste treatment, brought about by extensive research and active commercial development during recent years. That this condition is at hand is evidenced by the prominence of discussions in the current literature in which the recreational use of waters largely figures.

In Massachusetts the Merrimac River, long abandoned to municipal and industrial pollution and periodically investigated and approved, has at last been officially recognized as having values that exceed those based upon its use as a carrier of pollution. A. D. Weston (116) describes briefly, with all too meager analytical detail, the results of an extensive investigation inaugurated in 1923 which has apparently been continued to date. His conclusions are that the water enters the state from New Hampshire in a reasonably satisfactory condition (thus nullifying one of the standard objections against any attmept at improvement of this river within the state); that it carries a large amount of putrescible matter and large numbers of bacteria below Lowell; and that below Lawrence and Haverhill it has been in an objectionable condition. Alternative projects for relief, separate disposal at local treatment works, and a trunk sewer from Lowell to the sea with less intensive treatment at the outlet, are compared as to cost and utility, and the decision seems to be in favor of the latter project, largely upon the basis of more adequate protection of the recreational interests involved.

A report of a special committee on water pollution made to the National Resources Committee under date of November 11, 1935, attempts to evaluate in dollars the loss of recreational values resulting from stream pollution. It is held, for example, that on the upper Mississippi River damages to land suitable for recreational purposes may amount to as much as one and a half million dollars. Dealing with the waters of New Jersey it is stated that "The greatest damage from stream pollution is its interference with recreation. For many miles the streams of the state are so badly polluted that all thought of their recreational use has long since been abandoned." This same report deals likewise with actual monetary losses resulting from the destruction of wild life and especially the disappearance of fish and the incidental effect upon real estate values.

Nelson (117) reports upon an interesting investigation of bathing beach pollution at Kingsland Point in Westchester County on the Hudson River. In addition to its specific interest as a study of a local situation there is wider significance in the fact that several of the bathing

beaches established by the County Park Commission had been closed in 1933 by order of the County Health Department until adequate chlorination of the sewage of several of the larger nearby communities had been put into operation. It is of special significance to note that when faced with the alternatives the municipalities involved were quick to respond with the necessary remedial measures. Nelson's report gives a before and after picture of the situation at one of these beaches and amply justifies the measures that were adopted.

Acid Mine Drainage.—The committee report for 1934 briefly touched upon the beginnings of what has since become an important measure in the protection of some of the tributaries of the Ohio River against excessive pollution from the acid drainage waters of abandoned coal mines. A more complete and much more optimistic report has been issued by Tisdale and Lyon (118). The authors believe that activities carried on during the year in the State of West Virginia has satisfactorily demonstrated the practicability of the procedures of mine sealing which had been previously developed by laboratory research and field experimentation in the U. S. Bureau of Mines. The present report indicates that the active work of sealing abandoned mines has been closely followed by an analytical check-up so that the authors are in position to report not only upon the feasibility of the operation itself but also upon the measure of its effectiveness. It has been determined, for example, that in the case of the 215 mines actually closed there has been a reduction in the output of acid amounting to 78 per cent of the total. It is furthermore estimated that of the total acidity of all West Virginia rivers derived from coal mines, active, marginal and abandoned, 66 per cent is removable by appropriate measures, and that this task is about 10 per cent complete in terms of total acid or about 12 per cent in terms of abandoned mines. The authors undertake the difficult task of analysing the economic cost of acid pollution and arrive at certain significant figures, such as $500,000 annually in West Virginia for damage to concrete work on highway culverts, $25,000 annually for boiler water purposes on one railroad system, $50,000 annually for additional chemicals at three water treating plants. Summing up the economic loss in the state of West Virginia they estimate it conservatively at one million dollars annually. They also quote an estimated cost of $2000 per day distributed among the various public and industrial users of water along the 50-mile stretch of the Monongahela between the West Virginia line and McKeesport. In Ohio encouraging results are likewise reported, in the closure of 3548 abandoned mines at a total cost of $112,000. It is stated here that there has been a decrease of between 35 and 60 per cent of total acidity in the rivers and that the *annual* expense chargeable to the effects of acid water is many times the *total* cost of the preventive program.

Oil Pollution.—The extent and effects of various types of oil pollution and our meager present-day knowledge of remedial treatments are admirably discussed in a report of a special committee of the Conference of State Sanitary Engineers (119). Separate consideration is

given to the two types of pollution due to operations in the field and to refinery operations respectively. A third type of pollution, of growing prevalence, due to the accidental or willful discharge of oil or oil contaminated bilge and ballast waters from ships has not been considered.

Oil pollution from the oil fields affect water supplies by giving them oily or otherwise undesirable tastes and odors, and, under certain conditions, by the introduction of high concentrations of salt. The refinery wastes in addition are responsible for significant increases in B.O.D. and likewise in chlorine demand. Agriculture, stock watering, fish and shell-fish life and recreational uses of water are likewise affected.

Remedial and abatement methods have been developed to some extent, especially by the oil industry itself and the "Manual on Disposal of Refinery Wastes" of the American Petroleum Institute has become a recognized authority. Cooperation of industry is further shown in a report by Geiger (120) who was faced with a particularly serious situation due to the proximity of important oil field areas and valuable bathing beaches. He estimates that the industry expended in the neighborhood of two million dollars upon improvements and abatement methods consisting in the main in piping of waste waters to a disposal system where oily matters are separated.

In the states of Illinois, Indiana, Kansas, Oklahoma and Pennsylvania abatement activities have been carried out involving in some cases chemical treatment of the waters for the removal of odor-producing substances, various types of separating devices, impounding for release on flood waters and evaporation.

Irrigation Waters.—In a forceful presentation Chapman (121) raises the question of the use of polluted waters in irrigation in arid regions, with special reference to such practices in Colorado. It is well to recall that the early practice of broad irrigation or sewage farming was confined for the most part to the irrigation of fodder crops, although in the early development of this art in California it was extended to orchards of nut-bearing trees and citrus fruits and even, in some instances, to truck gardening. At the most, however, this latter was limited to those garden products which are ordinarily cooked and in more recent years California has much more strictly limited the use of sewage in irrigation (see section on Filtration). It comes as something of a surprise therefore to learn that under present-day conditions in Colorado, "That the grossest kind of pollution is possible under this system is shown by the fact that lettuce has been served in public eating places with feces adhering to the leaves." "Even vegetables which are grown many miles below the source of pollution were found to reek with colon bacilli, and after thorough washing the colon bacillus index in many instances was too high to pass them as fit for human consumption." The author makes out a somewhat meager statistical case in his graphs, showing the relative incidence of typhoid fever and of diarrhea and enteritis in Colorado, as compared with the United States

Registration Area and with certain nearby states likewise depending upon irrigation in agriculture. Colorado not only has had the highest average rates during the past eight years but shows the least decline in these rates during the past three years. The distribution of these diseases among the counties of the state appears to be somewhat closely associated with river pollution. The author concludes that the water supplies of the state are adequately safeguarded and the milk supplies, while not satisfactory, are reasonably uniform over the state. He urges protection of the streams from gross sewage pollution and the prohibition of the use of polluted irrigation water in the growing of such crops as strawberries, vegetables eaten raw or other vegetables, the handling of which in the household may lead to contamination of food.

Deoxygenation and Reoxygenation Formulae.—The extensive researches of the U. S. Public Health Service group at the Cincinnati headquarters of the stream pollution investigations, extending back to 1913, have included many studies, based on laboratory and field data, of the mathematical relations which have been found to express the various states of biochemical oxidation and of reaeration in the stream, under various conditions of concentration, temperature, and stream flow. The results have appeared from time to time in the various publications of the Service and Streeter (122) has recently brought together in brief and workable form that part of this accumulated material which represents our best present-day views of these various interrelations. The value of the work is greatly enhanced by the illustrative examples that have been worked out in detail for each case.

The nature of this series of publications precludes any useful digest that would be shorter than the paper itself and it may be frankly stated, both as an admission and a warning, that this material will be of slight interest to the amateur, and of little practical use in the ordinary so-called "stream survey." It is, however, of the greatest practical value to any competent persons desirous of obtaining some fundamental knowledge of any given stream stretch. In addition to reducing to their simplest possible form and illustrating by examples, the various complicated formulae involved, the paper serves the distinct advantage of suggesting to the investigator something of the minimum requirements of an adequate stream survey.

REFERENCES

1. THIS JOURNAL, **7**, 377 (1935).
2. *Jour. Ind. Eng. Chem.*, **27**, 683 (1935).
3. *Ibid.*, **28**, 79 (1936).
4. *Ibid.*, **28**, 83 (1936).
5. *Water Poll. Res. Bd.* (British) Tech. Paper 3 (1933).
6. THIS JOURNAL, **7**, 36 (1935).
7. *Ibid.*, **5**, 788 (1933).
8. *Bioch. Jr.*, **29**, 116 (1935).
9. *Water Poll. Res. Bd.*, Ann. Rept., 1934–35.
10. *Civ. Eng.*, **5**, 767 (1935).
11. *Jour. Am. Chem. Soc.*, **55**, 2012 (1933).

12. *Surveyor*, **88**, 629 (1935).
13. THIS JOURNAL, **7**, 417 (1935).
14. *Ges. Ing.*, **58**, 683 (1935).
15. THIS JOURNAL, **7**, 422 (1935).
16. *Ibid.*, **7**, 781 (1935).
17. *Proc. Inst. Sew. Pur.* (1935).
18. THIS JOURNAL, **7**, 96 (1935).
19. *Ibid.*, **7**, 3 (1935).
20. *Compt. Rend.*, **200**, 1886 (1935).
21. *Arch. Hyg.*, **114**, 209 (1935).
22. *Public Works*, **66**, 5, 15 (1935). Also *U. S. P. H. Reports*, **50**, 671 (May 17, 1935).
23. *Public Works*, **66**, 623 (1935).
24. *Annual Report, Manchester Rivers Dept.*, Mar. 28, 1928, p. 40.
25. *Compt. Rend.*, **200**, 1253 (1935).
26. *Proc. Inst. Sew. Purif.*, **1**, 123 (1934).
27. *Surveyor*, **86**, 510 (1934).
28. *Ibid.*, **88**, 609 (1935).
29. *Mich. Exp. Station Bull.*, **60**, (1935). Review, THIS JOURNAL, **7**, 768 (1935).
30. *Ges. Ing.*, **58**, 471 (1935).
31. THIS JOURNAL, **7**, 149 (1935).
32. *Ibid.*, **7**, 642 (1935).
33. *Ibid.*, **7**, 23 (1935).
34. *Ibid.*, **7**, 810 (1935).
35. *Ibid.*, **7**, 843 (1935).
36. *Ibid.*, **7**, 839 (1935).
37. *Ibid.*, **7**, 435 (1935).
38. *Ibid.*, **7**, 182 (1935).
39. *N. J. Agr. Exp. Sta.*, Bull. **589** (1935).
40. *Geneesk. Tydschr. Ned. Indië*, **75**, 1540 (1935).
41. *Water Works and Sew.*, **82**, 33 (1935).
42. *Ges. Ing.*, May 4, 1935—Translated THIS JOURNAL, **7**, 750 (1935).
43. *Eng. News Record*, **115**, 224 (1935).
44. *Ibid.*, **115**, 222 (1935).
45. *Ibid.*, **115**, 186 (1935).
46. *Ibid.*, **115**, 501 (1935).
47. *Water Works and Sew.*, **82**, 95 (1935).
48. THIS JOURNAL, **7**, 222 (1935).
49. *Water Works and Sew.*, **82**, 121 (1935).
50. *Ibid.*, **82**, 337 (1935).
51. *Ges. Ing.*, **57**, 323 (1934)—Abstracted THIS JOURNAL, **7**, 585 (1935).
52. THIS JOURNAL, **7**, 713 (1935).
53. Abstracted, THIS JOURNAL, **7**, 761 (1935).
54. *Water Works and Sew.*, **82**, 109 (1935).
55. *Ibid.*, **82**, 175 (1935).
56. *Ibid.*, **82**, 237 (1935).
57. *Ibid.*, **82**, 371 (1935).
58. *Ibid.*, **77**, 51 (1930).
59. *Ibid.*, **82**, 362 (1935).
60. THIS JOURNAL, **7**, 684 (1935).
61. *Amer. City*, **50**, 10, 17 (1935).
62. *Arch. f. Hyg.*, **114** (1935)—Abstracted, *Chem. Abs.*, **29**, 7541 (1935).
63. THIS JOURNAL, **7**, 852 (1935).
64. *Water Works and Sew.*, **82**, 226 (1935).
65. *Ges. Ing.*, **58** (1935); *Chem. Abs.*, **29**, 7541 (1935).
66. *Water Works and Sew.*, **82**, 47 (1935).
67. THIS JOURNAL, **7**, 166 (1935).
68. *Surveyor*, **88**, 43, 79, and 91 (1935).
69. THIS JOURNAL, **7**, 930 (1935).

70. *Ibid.*, **7**, 684 (1935).
71. *Ibid.*, **6**, 1054 (1934).
72. *Ibid.*, **7**, 17 (1935).
73. *Ibid.*, **7**, 928 (1935).
74. "Observations on the Biological and Physical Properties of Activated Sludge," Read at Glasgow, Scotland, July 2, 1926.
75. *Jour. Ind. and Eng. Chem.*, **22**, 1330 (1930).
76. THIS JOURNAL, **2**, 228 (1930).
77. *Ibid.*, **7**, 214 (1935).
78. *Ibid.*, **7**, 405 (1935).
79. *Ibid.*, **7**, 393 (1935).
80. *Water Poll. Res. Bd.* (British) Annual Report (1934).
81. THIS JOURNAL, **7**, 29 (1935).
82. *Jour. Ind. and Eng. Chem.*, **27**, 1228 (1935).
83. *Publicke Werken*, **3**, 93 (1933); Abstr., THIS JOURNAL, **7**, 133 (1935).
84. THIS JOURNAL, **7**, 70 (1935).
85. *Ibid.*, **7**, 658 (1935).
86. *Ibid.*, **7**, 597 (1935).
87. *Ibid.*, **7**, 611 (1935).
88. *Jour. Ind. and Eng. Chem.*, **27**, 218 (1935).
89. *Water Works and Sew.*, **81**, 403 (1934).
90. *Ibid.*, **82**, 323 (1935).
91. THIS JOURNAL, **7**, 1000 (1935).
92. *Ibid.*, **7**, 919 (1935).
93. *Ibid.*, **7**, 694 (1935).
94. *Ibid.*, **7**, 56 (1935).
95. *Ibid.*, **7**, 628 (1935).
96. *Ibid.*, **7**, 514 (1935).
97. *Public Works*, **66**, Nos. 7–11 (1935).
98. *Amer. Jour. Public Health*, **25**, 122 (1935).
99. *Water Works and Sew.*, **82**, 109, 175, 237 (1935).
100. *Ibid.*, **82**, 362 (1935).
101. *Municipal Sanitation*, **6**, 262 (1935).
102. *Water Works and Sew.*, **82**, 172 (1935).
103. THIS JOURNAL, **7**, 506 (1935).
104. *Ibid.*, **7**, 506 (1935).
105. *Water Works and Sew.*, **82**, 305 (1935).
106. THIS JOURNAL, **7**, 590 (1935).
107. *Public Works*, **66**, No. 10, 31 (1935).
108. *Water Works and Sew.*, **82**, 393 (1935).
109. THIS JOURNAL, **7**, 511 (1935).
110. *Mich. Eng. Exp. Sta., Bull.* **64**, 21 (1935).
111. THIS JOURNAL, **7**, 991 (1935).
112. *Mich. Eng. Exp. Sta., Bull.* **60** (1935).
113. *Eng. News-Record*, **803** (1935).
114. *Water Works and Sew.*, **82**, 331 (1935).
115. THIS JOURNAL, **7**, 35 (1935).
116. *Municipal Sanitation*, **7**, 18 (1936).
117. *Ibid.*, **6**, 329 (1935).
118. *Jour. Amer. Water Wks. Assn.*, **27**, 1186 (1935).
119. THIS JOURNAL, **7**, 104 (1935).
120. *Municipal Sanitation*, **5**, 305 (1934).
121. *Amer. Jour. Public Health*, **25**, 930 (1935).
122. THIS JOURNAL, **7**, 251 and 534 (1935).

CHEMICAL SEWAGE COAGULATION *

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I. Effect of pH

Some of the factors which affect sewage coagulation are still more or less obscure, while others are known to be of importance, but knowledge of the extent and the degree of their effects has not been made available. During the last few years considerable experimentation has been conducted in our laboratory and some of the work has been extended to plant scale trials. Among the factors studied were the effect on B.O.D. reduction of pH, length and degree of mixing, type of mixing, character and age of sewage, pre-settling, return of sludge, type of chemicals, relation between chemicals, additive agents and methods of application. In addition, studies were made of the relation between turbidity, suspended solids and B.O.D. removals. It is the intention to present information in a series of papers dealing with individual factors and combinations.

The present paper deals more specifically with the effect of pH changes on the removal of suspended solids in different sewages. Since the relationship between the various forms of iron salts will be discussed in another paper, the results presented here deal only with ferric chloride. The iron salt dosage was left constant, while the pH values were varied by means of sulphuric acid, lime and sodium hydroxide.

Procedure.—Samples of sewage were collected from New Brunswick, Highland Park, Joint Plainfield, North Plainfield and Dunellen, Hillsdale, Freehold and Red Bank, N. J.

The sewage of New Brunswick contains the wastes from a variety of industries, is rather weak and fairly fresh. Highland Park sewage is strictly domestic, fresh and somewhat stronger. Plainfield sewage is considered to be domestic, strong, stale and difficult to treat. The sewage from Hillsdale is from a large State Institution, fresh, with average strength. Freehold sewage, containing part of the waste of a large industry discharging soaps, dyes, alkalies, etc., is usually stale upon reaching the plant and of average strength. Red Bank sewage is domestic, stale and of average strength. An indication of the strength of the sewages used is shown in the following results of analyses of 24-hour composite samples.

For the purpose of determining the effect of chemicals with varying pH values, large catch samples were collected and 1½ liter portions of each sample were treated with 8.5 p.p.m. Fe in the form of $FeCl_3$. The sewages were adjusted over a pH range of from 2.0 to 11.0 by using sulphuric acid for the lower pH range and milk of lime to raise the pH

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Source	Suspended Solids P.p.m.	5-Day B.O.D. P.p.m.
New Brunswick	114	189
Highland Park	175	220
Plainfield	242	280
Hillsdale	156	235
Freehold *	232	260
Red Bank *	212	192

* Day sewage only.

to 9.5, on the alkaline side. For pH values above 9.5 sodium hydroxide was used in addition to lime previously added. This was necessary because the quantities of lime to raise the pH values above 9.5 were so large that they imparted a definite turbidity to the supernatant after settling. It should be pointed out that NaOH behaves differently and produces a different effect than lime, as will be shown later. After introduction of the chemicals, with thorough immediate mixing, a 20-minute period of slow mechanical stirring was followed by an hour of quiescent settling. All samples were mixed for the same period at 20 r.p.m. with the stirring apparatus developed by Dr. Lloyd R. Setter and shown in Figure 1, using cylindrical glass jars for containers. The

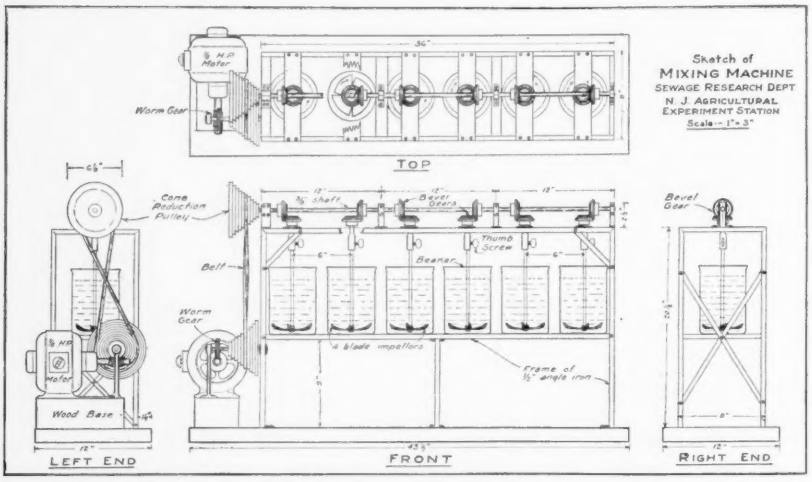

FIG. 1.—Stirring apparatus used in laboratory experiments.

stirring apparatus allows speed varying from 7 to 200 r.p.m. The actual stirrers are in the form of propeller blades, curving upward to impart a rotary, upward motion to the liquid.

Tests made to determine the purification produced, and thereby the efficiency of the treatment, consisted of turbidity, suspended solids and 5-day B.O.D. on all supernatants. Liquids with pH values below 4.0 and above 9.0 were seeded for B.O.D. determinations and water containing 200 p.p.m. $NaHCO_3$ was used for dilution. Turbidity was de-

termined in a calibrated lined Nessler tube. The amount of sample taken for suspended solids varied with the amount of solids present, so that by using aliquots from 50 to 200 c.c. sufficient solids were weighed to make the determinations reasonably accurate.

Results

Before a comparison is made between the different sewages it is essential to determine whether the effect of pH adjustment varies materially with the quantities of coagulant (iron salt) used. The general effect of adjusting the pH values upon the removal of suspended material, when different dosages are used, is shown in Figure 2. The greatest removals occurred at two points. These two points varied somewhat with the quantities of iron salt added; the larger the quantity of coagulant the nearer the optimum point moves to the neutral point. It will be shown later that the optimum points also vary somewhat with different sewages and the quantities and types of adjusting chemical added.

With the particular sewage used the greatest removals occurred between pH 3.0 to 3.5 on the acid side and pH 9.5 to 11.0 on the alkaline side. The less iron used the greater the necessity for close adjustment of pH to obtain optimum removals. This is well illustrated by the fact that with no pH adjustment and 15 p.p.m. iron, removals were less than with proper pH adjustment and no iron added. The less iron used the narrower and the further apart the pH ranges for optimum removals.

When excessive quantities of acid and alkali are added, the effluent becomes poorer. In the case of the acid a strong dispersing or rather peptizing effect was apparent at a pH value of 2.5, increasing greatly when the pH was lowered to 2.0. In the range below pH 3.0 relatively large amounts of acid were necessary to produce the desired changes. The peptizing effect is undoubtedly somewhat in proportion to the amount of acid added. The character of the sewage is also an important factor.

With increased quantities of milk of lime, suspended solids removal increases gradually until the quantity of lime becomes excessive, producing a turbidity of its own which interferes with the measurements employed. Sodium hydroxide does not produce the same effect as lime, but in order to determine the character of effluents at high pH values, NaOH was added after the pH had been adjusted to 9.5 with lime. When large quantities of caustic were added to reach very high pH values (pH 11.5 and above) large flocs or clots were formed which left a residual turbidity sufficient to produce effluents unsatisfactory from the standpoint of clarification. The increase in residual turbidity above pH 11.5 was not progressively greater with the increased amount of alkali added, as was the case with the acid, but the effluent remained turbid. The behavior of the acid and alkali was similar in all sewages used. The character of the turbidity produced by excessive caustic or acid appeared to be of a more finely divided nature than the natural turbidity due to lack of removal by the floc.

To determine the effect of $FeCl_3$ on coagulation, a strictly domestic sewage and four sewages obtained from different sources were used. Turbidity determinations were made on the treated effluents. The relation between turbidity, suspended solids and B.O.D. is shown in the second paper of this series. The characteristics of the five diverse sewage samples are shown in Table I.

TABLE I.—*Characteristics of Sewage Samples*

Source	Susp. Sol.	B.O.D.	pH	Remarks
	P.p.m.	P.p.m.		
Hillsdale	124	175	7.0	Fresh, traces of sulphides
Highland Park	178	216	7.2	" " " "
Freehold	412	500	6.7	Very stale, sulphides high, high soluble B.O.D.
Plainfield	710	400	7.0	Macerated, high in sulphides
Red Bank	512	410	7.0	Much grease, low in sulphides

It can be seen that the sewages varied materially in suspended solids, B.O.D. and sulphide contents. The results shown graphically in Figures 2 and 3 show that the weakest and rather fresh sewage

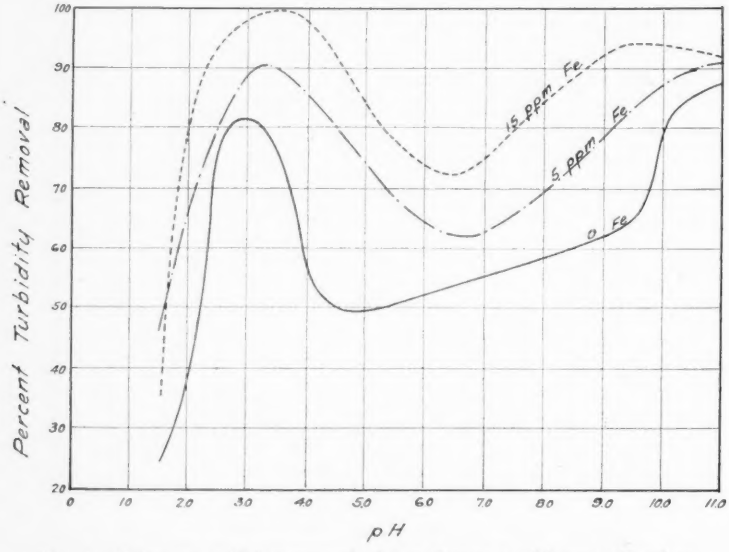

FIG. 2.—Effect on turbidity removal of iron dosage at different pH values.

(Hillsdale) responded to chemical treatment in the most clear-cut manner. The minimum percentage removal remained practically constant between pH 6.5 to 7.5, while the two optima were found to be at pH 3.5 and 10.0. With the increase in strength of the sewage (but fresh, Highland Park), the pH at which the minimum removal occurred was moved slightly to the acid side, while the optima were at some-

what lower and higher pH values than for the weakest sewage. With a further increase in strength of sewage (rather stale, Red Bank) the removal between pH values 4.5 to 10.0 was not greatly increased, so that the maximum removals occurred only at pH values of 2.5 and 11.0. The type of the curves remained in general the same. Very stale and strong sewage (Freehold) exhibits the same general curve, but the trend gradually changes with the increase in strength of sewage, until with a very strong sewage, containing much finely divided material on account of a long run through sewers, pumping, etc. and relatively large quantities of sulphides (7 to 10 p.p.m.), the curve flattens with a series of troughs or a repetition of minor peaks and valleys. The practical pH values to produce good removal are at pH 5.0 and 9.5, while the optimum removals are reached at pH 3.0 and 11.0.

In general the greatest percentage removals on the acid side occurred between pH values of 2.5 and 3.5. The percentage removals were all of about the same magnitude, although the best removal was secured (97.5 per cent) in a sewage of average strength. In the weaker and stronger sewages the peak of removals was about 90 per cent. Other and additional results indicate that the differences in the case of strong sewage are due to use of insufficient coagulant. It should be remembered that the iron salt dosage was kept constant for all sewages at 8.5 p.p.m. as Fe. The slightly lower percentage removal in the weaker sewage was due to insufficient suspended solids to form a floc of sufficient bulk to produce maximum removal with the constant time of settling employed (one hour). The range of pH values at which peak removal occurred is also wider for the medium strength sewage.

If it is correct that the addition of acid causes a peptizing effect, exhibited by an increase in turbidity, we should find not only a rise in turbidity with the greatest amounts of acid added, but the rise in turbidity should also be shown at a higher pH in the weaker than in the medium and stronger sewages.

This peptizing effect would be shown best after the optimum point of coagulation has been reached. As an example, the results on four sewages, with about equal quantities of original suspended solids, are shown in Table II. Only small differences in the quantities of acid

TABLE II.—*Increase in Turbidity on Addition of Acid (100% H_2SO_4)*

Susp. Solids, Raw Sewage	Parts per Million							
	257		272		281		301	
pH	Turb.	Acid.	Turb.	Acid.	Turb.	Acid.	Turb.	Acid.
	P.p.m.	Cc.	P.p.m.	Cc.	P.p.m.	Cc.	P.p.m.	Cc.
3.5	20	0.21	—	—	—	—	—	—
3.0	22	0.23	5	0.2	20	0.27	35	0.23
2.5	33	0.45	16	0.3	25	0.50	45	0.45
2.0	100	1.00	31	0.6	81	1.00	120	1.00
1.5	—	—	142	2.5	128	2.50	160	2.50

were required to obtain the same pH values in these different sewage samples. After the optimum pH for best coagulation is reached the turbidity increases with the quantity of acid used but not necessarily in direct proportion. The increase in turbidity is undoubtedly related to the character of the sewage, which in turn affects the stability of the chemical floc and the degree of peptization.

The rise in the percentage increase in turbidity, as shown by the curves, was most marked in the weakest, less in the medium and least in the strongest sewage. The actual quantity of dispersed material appears to remain constant when the concentration of the suspended solids is decreased by the settling of settlable solids. As an example the mean results of four determinations with varied settlable suspended solids obtained by pre-settling are shown in Table III. The point of maximum removal occurred in all instances at pH 3.0.

TABLE III.—*Effect of Varying Settlable Solids*

P.p.m. Susp. Solids	P.p.m. Turbidity at		P.p.m. Turbidity Increase
	pH 3.0	pH 2.5	
150	28	42	14
330	27	44	17
570	26	40	14

By decreasing the pH value by an increment of 0.5 the increase in turbidity remained constant. It appears therefore that the acid acts on a certain portion of the finely divided suspended solids, causing redispersion, giving more evidence that in coagulation the interest lies specifically with the finely divided solids and that the character of the solids is of importance. The question of the value of pre-settling will be discussed later in more detail.

By raising the pH values with lime a steady rise in the removal of suspended solids occurred up to pH 9.5, which was the practical limit for lime addition. Again, best results in terms of percentage removals were obtained in the medium strength sewage, where removal at pH 9.5 was 90 per cent as compared to 78 per cent in the weak and 74 per cent in the strong sewage (Figure 3).

This is decidedly a more marked difference than was evident on the acid side. Here several factors may account for the difference in the percentage removal. From data at hand we know that when lime and iron are used for coagulation the amount of suspended solids present in finely divided form is an important factor in the removal. Settlable or coarse solids are of little importance in this respect, because they are removed mechanically. The iron coagulant requirements of the different classes of suspended solids will be discussed in a subsequent paper. It is sufficient to state at present that there is a medium concentration of finely divided solids where best removal occurs. This effect is not evident at the peak of removals when low pH values are

employed. In addition to the effect of finely divided suspended solids concentration, the soluble materials present may exhibit a similar concentration action. Furthermore, factors such as iron salt deficiency

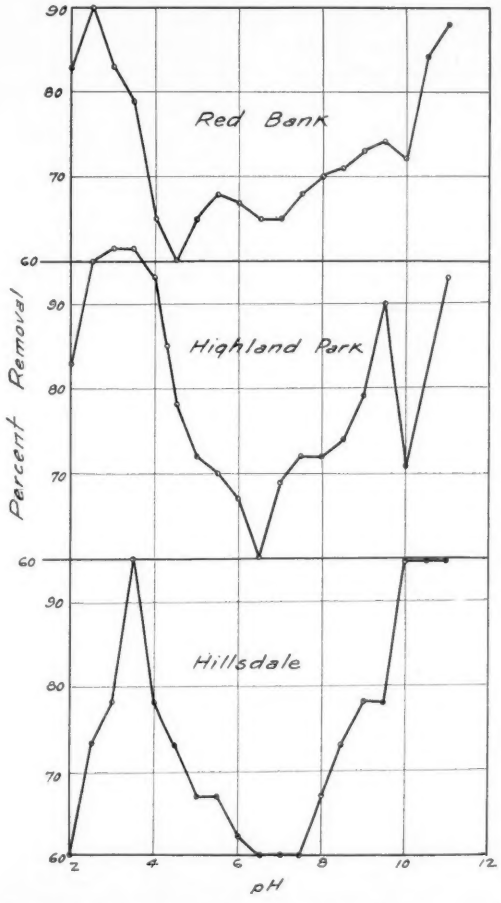

FIG. 3.—Relation between pH values and turbidity removal.

in the case of strong sewages, degree of fineness of material in weak sewages, etc., play a role in reducing the removals of absolute quantities of suspended solids as well as the percentages.

In general high removals occur in all sewages at pH values 10.5 to 11.0, but the magnitude changes somewhat with the character of the sewage. When weak, medium and strong sewage samples from the same source are used, the percentage removals are in the order of the strength of the sewage, *i.e.*, the highest percentage removal occurs with the weakest sewage, provided the same quantity of coagulant is used and the same pH value is employed.

Attention is called to a peculiar phenomenon occurring in all sewages at pH values 9.5 to 10.0. Examination of the curves reveals a more or less pronounced drop in the percentage removal of suspended solids at these pH values, usually followed by a steep rise in the curves. Repetition of the tests showed that this drop in removals followed by a rise at pH 10.5 to 11.0 occurred persistently in all sewages tried, with very little variation in the magnitude of the changes for each particular sewage. The extent of the drop is dependent on the type of the sewage.

There is no apparent relation between the quantity of suspended solids or B.O.D. of the sewages and the extent of dips and rises in the percentage removal curves, when comparing different sewages. However, with an increase in staleness and degree of maceration of solids, the number of dips and rises increase over the whole range of pH values. If it is assumed that the greatest percentage removal occurs at the so-called "iso-electric" point of the sewage, maceration would result in greater division of solids and presumably in increased production of colloids with different "iso-electric" points, while partial bio-

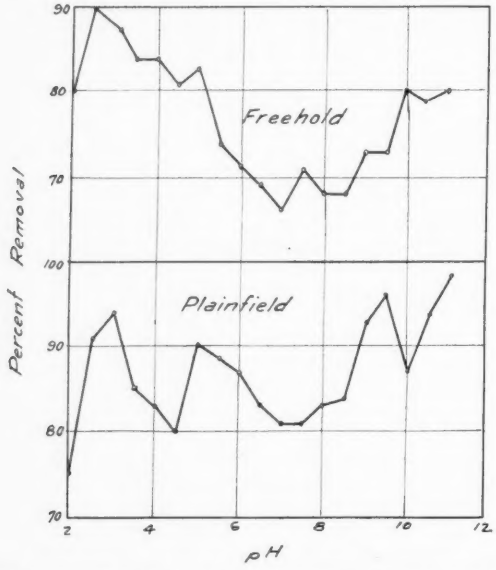

FIG. 4.—Relation between pH values and turbidity removal in strong and/or stale sewage.

logical decomposition might result in production of salts of varying buffering effects and combining powers. The further the partial biological decomposition progresses the greater the shift would be from the original "iso-electric" point, or the more specific substances are changed, the greater would be the number of points at which partial coagulation will occur. Referring to the increase in optima shown in the curves, it is clear that with the increase in staleness of the sewage such an explanation would fit. At the same time any trade waste added

may materially influence the shift in "iso-electric" points, or in other words, affect the degree of coagulation when different quantities of coagulant are added at a given pH value. This again is shown in the curves presented. Nevertheless, all sewages experimented with produce the same type of curve, so that for a particular sewage the optimum conditions for coagulation can be speedily determined. The determination of optimum conditions, as far as pH and iron salt are concerned, would be simplified if a rapid method were available to determine the iron demand of the particular sewage. It will be shown in subsequent papers that definite relations can be established between the iron demand and results of certain analyses made on the sewage.

Discussion

From the standpoint of practical chemical coagulation of sewage a number of factors are of importance. Before much advancement can be made it is essential to know more about the basic principles involved. It is virtually impossible to present all factors at one time and to reach conclusions that will adequately cover the work involved. A series of short papers will therefore be published, showing the effect of several factors, how they are modified, how they are related to findings in other fields and what their practical importance is in treatment of sewage. By presenting results obtained with sewages collected from different sources, ranging from fresh, weak domestic to very stale sewage, extremely difficult to treat, it is hoped that ultimate conclusions will have greater and more general value.

In sewage coagulation there are in general two zones of pH values where optimum removal of suspended solids takes place. These zones are shifted or modified with variations in septicity, quantity and type of trade waste, and quantity of iron coagulant used. The effect of the quantity of iron coagulant is much less important than the effect of septicity of the sewage. Maximum removal of suspended solids is greater in the acid than in the alkaline range. From a practical standpoint the range to be used in fresh sewage coagulation will therefore depend upon factors such as the initial pH of the sewage, ease of application and degree of corrosion of sewage works structures. Coagulation of stale sewage, containing large quantities of finely divided suspended solids, is probably accomplished most successfully in the alkaline range. However, several other factors may modify this conclusion.

Perhaps the most important conclusion to be drawn from the results presented is that all sewages behave fundamentally the same when iron coagulants are used, but that results obtained will vary with the type of sewage to be treated.

Summary

Sewages obtained from five different municipalities were treated with iron salts over a pH range of 2.0 to 11.5. Turbidity measurements were used to determine the degree of clarification. It was found that

optimum clarification occurred in two zones or pH ranges, one on the acid side and the other on the alkaline side, namely at pH values of 2.5 to 3.5 and 9.5 to 10.5. The optimum points of coagulation shift or are somewhat modified with variations in septicity, quantity and type of trade waste, and quantity of iron coagulant used. The reasons for the shifting of the optimum point of coagulation are discussed. Acid used for pH control appears to have a peptizing action on a certain portion of the finely divided suspended solids, and remains constant with a given quantity of acid.

II. Relation Between Turbidity, Suspended Solids and B.O.D.

In the preceding paper the clarification of sewage by $FeCl_3$ coagulant at different pH values has been studied by measuring the removal of turbidity. In sewage coagulation we are particularly interested in the removal of finely divided suspended material which ordinarily will not settle during the usual detention time provided. Removal of total suspended solids, however, is more frequently used to determine efficiency of clarification, while B.O.D. reduction is used as an index of the removal of putresible material and stability of the effluent. It is therefore, of considerable interest to know whether a simple turbidity determination will give an indication of the removal of suspended solids and of oxygen demand when coagulants are added.

Procedure.—Samples of sewage collected from five different municipalities, varying in strength and staleness, were treated with and without ferric chloride as a coagulant over a pH range of 2.0 to 11.5. For lowering of the pH values sulphuric acid was used, while milk of lime was employed to raise the pH values to 9.5. For pH values above 9.5 sodium hydroxide was used in addition to the milk of lime. After introduction of the chemicals the sewages were mixed rapidly, followed by 20 minutes mechanical stirring at 7 r.p.m. The coagulated sewage was then allowed to settle for a period of one hour.

Tests made consisted of determinations of turbidity, total suspended solids and 5 day B.O.D. on the effluents. Liquids with pH values below 4.0 and above 9.0 were seeded for B.O.D. determinations and water containing 200 p.p.m. $NaHCO_3$ was used for dilution. Turbidity was determined in a calibrated, lined Nesler tube. Suspended solids were determined on varying amounts of aliquots, depending upon the quantities of suspended solids present.

Results.—As an example of the close agreement between total suspended solids and turbidity in chemically treated effluents over the pH range employed, resulted, a series of tests are shown in Figure 5. The turbidity, expressed in p.p.m. remaining in the effluent, runs slightly higher than total suspended solids. This may be in accord with the fact that small quantities of very finely divided suspended solids pass through the mat in a gooch crucible and are included in turbidity measurement, but turbidity varies also somewhat with the size of the floc. For these reasons we can not attach much significance to slightly higher

turbidity readings. At the same time the size of the floc varies with the chemical dosage, type of mixing, pH range, etc. When the effluent is distinctly turbid and passage through a gooch crucible leaves only traces of suspended solids on the mat for weighing, the turbidity

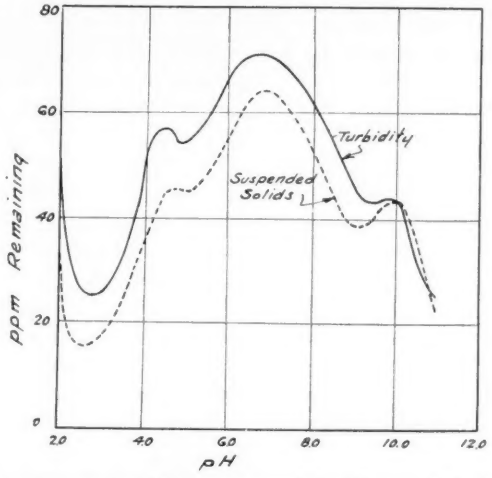

FIG. 5.—Relation between turbidity and suspended solids remaining in the effluents.

method of ascertaining small quantities of suspended solids present in chemically treated sewage is perhaps better than the weighing of the previously dried material.

Our experiments show that under certain conditions the effluent remained turbid, yet in filtering 200 c.c. samples no weighable amounts of solids were collected. The dispersing and/or peptizing effect of the chemicals upon the suspended solids is an important factor in such determinations. Occasionally, a sample shows a light pin-point floc in a clear liquid. This floc does not appreciably impair visibility, but is measurable as suspended solids. This condition occurs at low pH values, whereas the reverse occurs more frequently at high pH values. Differences between total suspended solids removal and turbidity measurements may also be affected by the fact that on drying the suspended solids a fraction of the material volatilizes, making the suspended solids determination less reliable. In addition, the turbidity measurement is less readily affected by sampling than the suspended solids determination.

The curves indicate a very close agreement between suspended solids and turbidity removals at pH values 9.5 to 11.0. In order to obtain pH values above 9.5 the calcium hydroxide was supplemented with sodium hydroxide. As pointed out in a previous paper, the NaOH behaves differently than the $Ca(OH)_2$. In these ranges the finely divided particles are readily flocked out by the combination of chemicals, resulting in readings of turbidity and determination of suspended solids which are almost identical.

The mass of results obtained in the operating pH range shows the same relationship as shown in the figure for the much wider range of pH values. Of greatest interest is the fact that the relation between turbidity and suspended solids in the effluent of chemically treated sewage does not materially change with different sewages. The difference in p.p.m. between turbidity and suspended solids of a chemically treated stale sewage may be somewhat larger than of a fresh sewage treated in the same way, or the difference may be slightly less with larger dosages of chemicals, but ordinarily the difference between the suspended solids and turbidity remains rather constant for a given sewage or for a given type of treatment. This enhances the value of the turbidity method materially for rapid determination of coagulant dosage and for an indication of probable clarification results to be obtained.

The method has been applied to plant operation and found to be applicable in every instance. Application at one place where strong stale sewage was treated over a period of six months showed that the average variation between turbidity and suspended solids was 4 per cent, while operation results at another plant over a period of three months where a medium, rather fresh sewage is handled, showed an average variation of 3 per cent. At still another plant where medium strong, somewhat stale sewage is treated, the results to date are equally satisfactory. The operating results obtained at one plant varied between 60 and 90 per cent suspended solids reduction, while at another the variations were between 68 and 92 per cent suspended solids reduction. The maximum difference between suspended solids and turbidity occurred at the lower suspended solids removals. These results indicate a close agreement obtained under operating conditions and those found in the laboratory.

Turbidity and B.O.D.—The relation between turbidity removal and biochemical oxygen demand reduction is much less close than between turbidity and suspended solids. An example of the relation between the percentage turbidity removal and the percentage B.O.D. reduction is shown in Figure 6. In general there appears to be a relationship, and B.O.D. reduction was largest when the largest amount of turbidity was removed. The example shown deals with average results obtained with a number of domestic sewages. The general relationship holds for results obtained at low and high pH values, but becomes less regular. With increase in staleness of sewage the relationship becomes less and less clear. This is illustrated by the results obtained on five different types of sewages coagulated at low and high pH values (Table IV). It is true that in general less turbidity remains with a greater percentage B.O.D. reduction, but the relationship changes in degree with increases in removal. This is due to the variation in the quantity of B.O.D. present as residual B.O.D. The residual B.O.D. is caused both by soluble material and suspended solids; with the removal of practically all suspended matter the remaining B.O.D. is caused by material in solution. This material in solution would have to be subtracted to allow formation of a base line for comparison. Without a

mass of results available from a number of plants under different conditions, the projection of a base line is of little practical interest.

The fact that under different conditions varying quantities of residual B.O.D. are present brings up two questions, first, can chemical

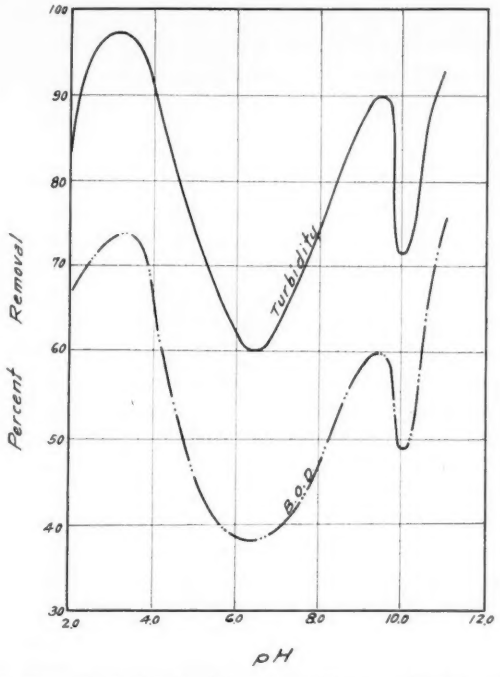

FIG. 6.—General relationship between turbidity and B.O.D. removal.

treatment remove some or all of the soluble B.O.D. in addition to suspended solids, and second, are considerable quantities of substances rendered soluble by the chemicals added, thereby increasing the residual B.O.D.?

TABLE IV.—*Relation Between Turbidity Remaining and B.O.D. Removal in Acid and Alkaline Ranges*

Sewage	pH	2.0	2.5	3.0	3.5	4.0	9.0	9.5	10.0	10.5	11.0
Freehold	Turbidity, p.p.m.	56	25	35	45	46	76	75	55	58	55
	B.O.D., %	35	48	45	30	24	20	26	36	30	42
Hillsdale	Turbidity, p.p.m.	40	25	20	5	20	20	20	5	5	5
	B.O.D., %	54	75	70	73	67	63	60	71	69	69
Plainfield	Turbidity, p.p.m.	84	40	30	55	62	34	25	50	30	20
	B.O.D., %	65	70	82	67	72	77	81	74	85	81
Highland Park	Turbidity, p.p.m.	35	10	5	5	15	44	20	60	—	15
	B.O.D., %	67	71	73	74	59	50	60	49	—	80
Red Bank	Turbidity, p.p.m.	40	25	42	51	85	65	62	68	39	28
	B.O.D., %	68	76	66	66	57	35	44	55	48	61

The first question is concerned with the nature of the soluble solids. The evidence to date shows that the chemicals employed are capable of reducing the soluble B.O.D. only to a small extent, but further work under way may modify this statement. However, with increased staleness, resulting in increased soluble B.O.D., no substantial removal seems to occur. The second question is under investigation and it seems doubtful that considerable quantities of materials are rendered soluble by the chemicals added to a domestic sewage in the working range (3.5–9.5) of pH values.

Discussion

From the results obtained it appears that with chemical treatment the quality of the effluent and the efficiency of the treatment can be judged quite accurately and rapidly by turbidity measurements. Suspended solids removal can be estimated from the turbidity figures so that the turbidity measurement can be used as a rapid tool for operation and control. In general there is also a relation between the removal of turbidity and B.O.D. reduction. It is evident that the average results on a number of sewages, or the average results on a particular sewage may show a more or less definite relationship between turbidity and B.O.D. reduction, but that individual tests or even groups of tests may show considerable fluctuation. This is more specifically the case where a high degree of treatment is practiced. With partial chemical treatment the relationship between turbidity and B.O.D. is closer, but here again the character of the sewage, staleness, presence of considerable quantities of trade wastes, etc. play a role. Although turbidity measurements are of some value and are desirable because of their simplicity, they are of little practical importance where more specific results are required. Nevertheless, such a simple and easy determination may conservatively aid in operation and in saving chemicals, since adjustments can be made immediately to suit conditions.

In operation, the type and character of the floc formed is used as an indication of the effectiveness of the coagulant used. As will be shown later the character of the floc varies with the kind and amount of coagulant used, as well as with the type of sewage treated. Routine pH determinations of the effluent afford control of treatment, since the pH value of the effluent is practically identical with the pH value of the mixed liquor. The simple turbidity measurements of the effluent and pH determinations of the sewage and effluent give the operator two handy tools, whereby the process can be controlled and the dosages of chemicals regulated with a good measure of dependability. An almost exact relationship existed between the pH of the sewage chemical mixture and the effluent pH values throughout the entire series of experiments. This checks with plant observations made at various places.

Summary

Comparison of turbidity measurements with total suspended solids removal in chemically treated sewage effluents shows a definite relation-

ship over the entire pH range tried (pH 2.0–11.0). For practical purposes the relationship holds for different types of sewages as well as for sewages of different character. There is a general relationship between the quantity of turbidity remaining and the amount of B.O.D. removed, but the relationship is affected by the age of the sewage, quantity and type of trade waste present, etc. Together with pH determinations of the sewage and effluent, the turbidity measurement is a simple and easy tool to control the process and regulate the chemical dosage.

CARBON DIOXIDE PRODUCTION IN MIXTURES OF SEWAGE AND ACTIVATED SLUDGE *

By H. Heukelekian

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A number of important contributions have appeared on the oxygen demand of sludges, particularly dealing with activated sludge. The earliest contribution to this subject was made by Grant, Hurwitz and Mohlman.[2] They discussed in detail the difficulties involved in the direct measurement of the volume of oxygen absorbed and to overcome these difficulties they developed a method in which they determined the dissolved oxygen content of the liquor, which was kept under aerobic conditions for definite intervals of time with constant stirring. Theriault and McNamee[7] introduced air into the mixture in a closed system and determined the oxygen absorption by analysis of the gas. Oxygen was determined by the Winkler method after it was dissolved in water. Some results on the initial oxygen demand and the reduction of oxygen demand on aeration obtained by the B.O.D. dilution method were presented by the present author.[3] Oxygen utilization by activated sludge was also studied by Kessler and Nichols,[4] by measuring the rate of disappearance for short periods of time of dissolved oxygen either present in the sludge initially or added to it by the dilution water or aeration. Burtle and Buswell[1] made measurements of the direct oxygen absorption by sewage and other materials by the Nordell apparatus, a full description of which is given in the article.

Finally, as a result of the work at the London School of Hygiene under the direction of Topley, the Water Pollution Research Board[5] considered the B.O.D. and the other available tests not entirely satisfactory for the purpose of study of purification of sewage by the activated sludge process. They determined the rate of oxygen absorption by the Barcroft respirometer, which measures the volume of oxygen absorbed by use of a manometer.

It will be seen from this brief discussion that there has been a need for a rapid and accurate method of determining the rate of oxidation of sludges. All the methods, however, have been based on measurements of the oxygen absorbed, with or without dilution, and either by measurement of the volume of gas or by volumetric determination of dissolved oxygen. It seemed to us that in spite of the variety of methods available there was an actual need for a less complicated and less expensive apparatus than indicated by most of the above methods. This new method should also be free from the objectionable features of the regular B.O.D. determination or the short period of contact of undiluted samples.

The production of CO_2 has been extensively used in microbiological

* Journal Series Paper, New Jersey Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

and in biological studies for determination of the rate of oxidation of organic materials. The equipment necessary for this determination is relatively inexpensive and the method is simple. Dilutions are not necessary and large volumes of the test material can be used. It is true that this method does not measure directly the oxygen consumption but only the product of oxidation. But since there is a direct relationship between oxygen consumption under aerobic conditions and CO_2 production, it can safely be used for determining the rate of oxidation. Generally the ratio of CO_2 production to O_2 consumption (respiration quotient) is 1:1, in substances similar to sugars in their composition. However, under certain conditions and with some compounds such as fats, ratios as low as 0.7:1.0 have been observed. Whenever the ratio is less than 1:1 some of the carbon must be left in the medium as organic acids or other incomplete products of oxidation. For this reason, until further investigations show the exact ratio it may not be safe to convert the CO_2 production values directly to oxygen consumption.

This method, as far as we are aware, has not been applied in investigations of the rate of oxidation of sewage and sludges in aerobic systems. The following investigation was therefore undertaken for the purpose of evaluating the rate of oxidation of such materials by the use of an index of CO_2 production.

Methods

The method employed in this laboratory consists in placing the test material in appropriate tubes fitted in the bottom with fritted-glass filter crucibles for air diffusion. The top of the tube is connected to a suitable gas absorption device. In this laboratory we use for this purpose a 25 c.c. capacity 10-bulb gas absorption tube, as indicated in Figure 1. When the CO_2 production is high, such as in activated sludge mixtures, an additional reservoir is placed ahead of the absorption tube. The absorption tube is filled with standard barium hydroxide solution (.1 N or .2 N). For sewage one-liter quantity is convenient, while for sludges 100 to 200 c.c. will be found to give sufficient CO_2. The size of the tubes will therefore depend on the type of material to be tested. Air freed from CO_2 is bubbled through the test material and the CO_2 evolved is absorbed in the barium hydroxide solution in the absorption tubes. At suitable intervals the CO_2 produced can be determined by titrating with standard oxalic acid, using phenolphthalein as indicator. Aeration can then be continued as long as necessary, with as frequent intervals of determining the amount of CO_2 produced, as is desirable. A series of these units were set up in a 20° C. incubator.

The general method of setting up an experiment was as follows: Different amounts of returned sludge were introduced into sewage and placed in the apparatus described above. For each series the rate of CO_2 production from the sewage and returned sludge alone was also determined.

These experiments were started in October, 1933, and continued with interruptions until November, 1934. All samples of sewage were obtained from Plainfield, N. J., and all the returned sludge, with one

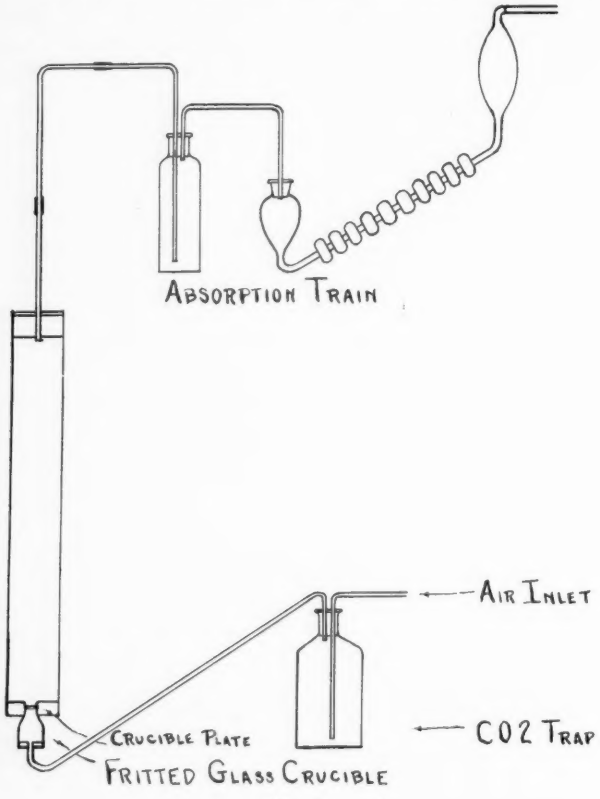

Fig. 1.

exception, from the Tenafly, N. J., activated sludge plant. In Series IV the returned sludge was obtained from the Hillsdale, N. J., institutional plant.

Results

Comparison of the Rate of Oxidation by the B.O.D. and CO_2 Production Methods

A comparison of the oxidation rates of sewage, activated sludge and fresh solids is given in Table I. The fresh solids were diluted with tap water to approximately the same concentration as the activated sludge. B.O.D. determinations were made at daily intervals for five days, of the initial materials and the material after five days of aeration. The CO_2 production was measured. The carbonate content and the pH value of the materials were also determined.

The oxidation of the sewage and activated sludge was consistently

TABLE I.—*Comparison of the Rate of Oxidation as Measured by CO_2 Production and B.O.D.*

Days	Sewage *						Activated Sludge *						Fresh Solids *					
	Initial	1	2	3	4	5	Initial	1	2	3	4	5	Initial	1	2	3	4	5
CO_2 mgm./L		151	234	318	362	415		1910	2900	3700	4150	4600		738	1420	2030	2320	2550
B.O.D., initial, p.p.m		120	200	255	—	365		890	1880	2240	—	3480		845	1760	2240	—	—
Ratio $\frac{CO_2}{B.O.D.}$		1.26	1.17	1.41	—	1.13		2.14	1.54	1.65	—	1.32		.87	.81	.91	—	—
B.O.D. after 5 days aeration, p.p.m.		23	35	47	—	60		180	320	535	—	780		1155	1635	2040	—	2600
Initial B.O.D. minus B.O.D. after 5 days aeration		97	165	208	—	305		710	1560	1700	—	2700		+310	125	200		+50
O_2 demand satisfied during aeration, per cent		80.8	82.5	81.6	—	84.7		79.7	83.0	76.0	—	77.6		—	—	—	—	—
Per cent of 5-day O_2 consumption per day		31.8	54.0	68.0	—	100		26.3	57.8	63.1	—	100		—	—	—	—	—
Per cent of 5-day CO_2 produced per day		36.5	56.5	76.5	87.5	100		41.4	63.0	80.5	90.5	100		28.9	55.7	79.6	91.0	100
Carbonates in solution, p.p.m. $CaCO_3$	145	—	—	—	—	150	205	—	—	—	—	85	225	—	—	—	—	200 —
pH	7.2	—	7.8	—	—	7.8	6.8	—	7.4	—	—	6.4	5.4	6.6	7.2	—	—	7.2

* Suspended solids, p.p.m.
Sewage = 190.
Activated sludge = 4665.
Fresh solids = 3650.

higher, as measured by CO_2 production, than by the B.O.D. The CO_2: B.O.D. ratio of sewage varied between 1.41 and 1.13. In the activated sludge the ratio was 2.14 initially and 1.32 at the end of five days. These differences should be attributed to acceleration of oxidation by the aeration employed for CO_2 determination. It has been claimed that, above a minimum oxygen tension, the rate of oxidation is not affected by the dissolved oxygen content of the menstruum. However, in the aeration process a more intimate contact is produced between the bacteria and their food, resulting in an accelerated oxidation. In the B.O.D. determination a partially anaerobic stabilization of the material settling to the bottom may take place, resulting in a lower oxygen demand. One or both of these factors may explain the generally wider CO_2: B.O.D. ratio of activated sludge over sewage. Results reported elsewhere [3] indicated that the aeration of sewage for 48 hours resulted in a greater percentage decrease of B.O.D. (av. 52.1 per cent) than similar aeration of returned sludge (av. 31.2 per cent). Since the comparisons made at that time were based on oxidation of the materials by the B.O.D. method, before and after aeration, the results are not necessarily contradictory to the present observation. When similar comparisons are made for the present study by comparing the B.O.D. before and after aeration, we find that sewage on the fifth day of aeration had 84.7 per cent of the initial 5-day B.O.D. satisfied and activated sludge only 77.6 per cent. With a shorter period of aeration, as in the previous study, the differences would probably have been greater.

The rate of oxygen consumption per day, as determined from the amount of oxygen taken up by the materials before and after aeration, compares closely with the percentage of the 5-day CO_2 produced per day, in the case of sewage. For activated sludge the rate of oxidation as measured by CO_2 production is higher than the rate of O_2 up-take during aeration.

The carbonate content of sewage did not decrease with aeration, while in activated sludge aeration a 120 p.p.m. loss of carbonates was observed. This would account for only 52.8 p.p.m. of CO_2, which would not be sufficient to account for the large differences between CO_2 production and B.O.D. in this material. The pH of activated sludge, after rising from 6.8 to 7.4 in two days, dropped to 6.4 after five days of aeration, indicating probably that nitrification had set in.

In the case of fresh solids the B.O.D. for the first three days was higher than the CO_2 production during the same period, resulting in a CO_2: B.O.D. ratio of less than unity. The B.O.D. of this material after five days of aeration was not materially lower than before aeration. In fact, the 1-day and 5-day B.O.D.'s were actually higher after aeration than before. This interesting contrast with the results obtained with sewage and activated sludge would indicate that CO_2 production was retarded by the low initial pH and the lack of suitable oxidizing flora. The initial B.O.D.'s of this material were approximately the same as the initial B.O.D.'s of the activated sludge, indicating that the

factors retarding the CO_2 production from this material were not so important for the B.O.D. determination. The pH is regulated in the B.O.D. determination by the sodium bicarbonate dilution water. The increase of the B.O.D. after five days of aeration over the initial B.O.D. might be ascribed to the greater rate of oxygen consumption by the products of decomposition liberated during aeration. The rate of CO_2 production from this material was lower initially than from sewage. After the second day the rates from all three materials approached each other. The activated sludge, in spite of the previous oxidation process which presumably would remove the readily oxidizable material, exhibited the greatest rate of CO_2 production during the first two days. The oxidizing flora already established in this material would offer the necessary explanation of this phenomenon. In the aeration of sewage the pH was not a limiting factor but the low rate of CO_2 production was probably caused by the deficiency of the oxidizing flora. In the fresh solids both the initial pH values and the bacterial flora were unfavorable for oxidation.

CO_2 Production from Sewage and Activated Sludge Mixtures

Eight series of experiments were conducted, using eight different lots of sewage and returned sludge. Only two of the series are given

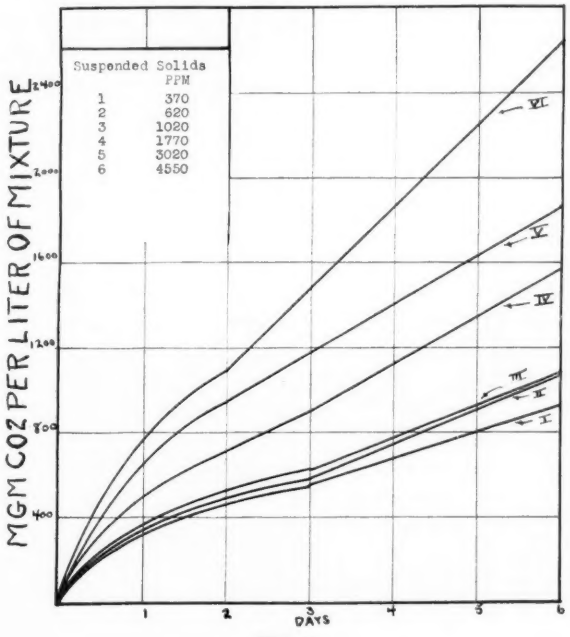

FIG. 2.

in Figures 2 and 3, which represent the cumulative CO_2 production per liter of sewage and sludge and their various mixtures. It will be seen

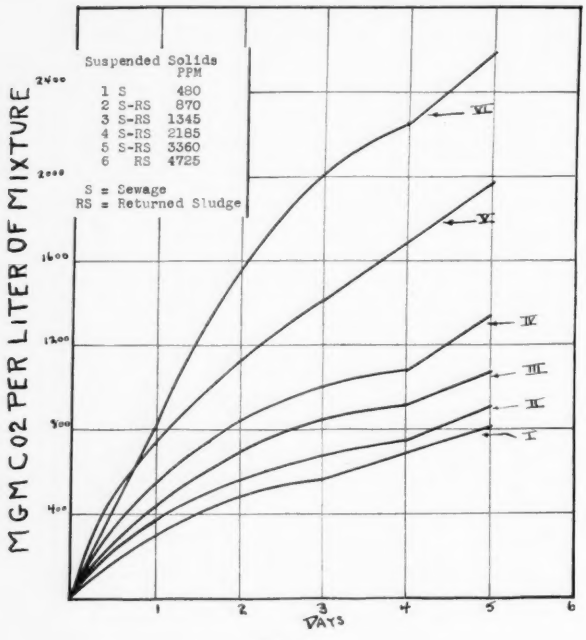

FIG. 3.

that CO_2 production increased with increasing amounts of returned sludge added to the sewage. The inflection of the curves changed after the third and fourth days, corresponding possibly to a similar change in the inflection of the B.O.D. curves observed with longer periods of incubation, which is usually ascribed to the change from the stage of the decomposition of carbonaceous materials to the decomposition of nitrogenous materials.

It is of interest to observe also that in five days the two sewages alone produced 800 mgm. of CO_2 per liter. If we apply the CO_2 produced to oxygen consumed ratio of 1 this would correspond to a B.O.D. of 800 p.p.m., which is somewhat higher than the expected B.O.D. for sewages of such strength. It has already been shown, however, that CO_2: B.O.D. ratios for sewage are higher than one.

The CO_2 productions from the eight different sewages used in the course of these experiments are assembled in Figure 4. In order to put them on a more or less comparable basis the results are expressed as mgm. CO_2 produced per mgm. suspended solids. It was not expected that such an expression would do away with the other variables in the sewage, such as the amount of organic colloidal and soluble materials. Thus we observe variations of from 1.4 to 3.6 mgm. CO_2 per mgm. suspended solids in four days. Similar variations are observed when the CO_2 production per mgm. suspended solids of the various returned sludges are compared, as in Figure 5. Here the 4-day values for the

different sludges fall between 0.10 and 0.48 mgm. of CO_2 per mgm. suspended solids. These values correspond closely to the B.O.D. values obtained by the dilution method.[3]

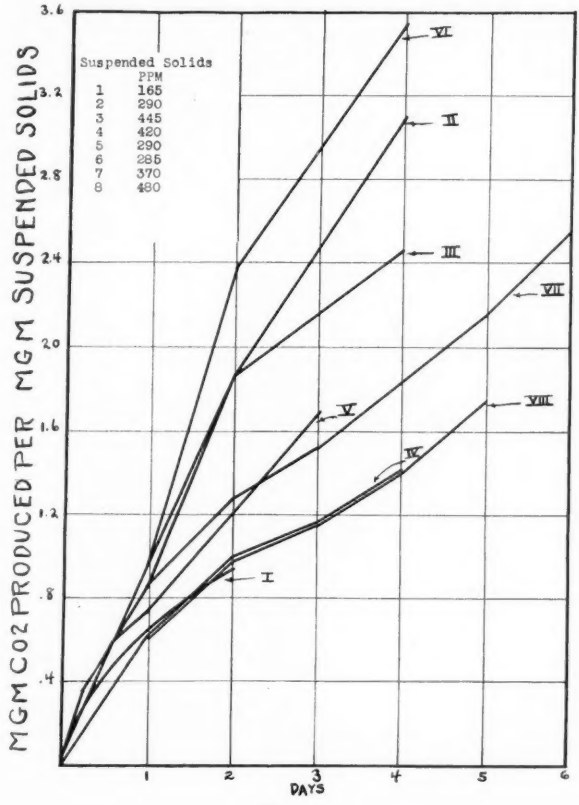

FIG. 4.

The differences in the rate of CO_2 production of the various samples of sewage and sludge should be attributed to differences in the character of the materials. Even in a given plant the character of the sewage changes rapidly. The stage of oxidation of activated sludge is also subject to fluctuations. The suspended solids of the different sewage samples varied from 165 to 480 p.p.m. without any correlation with the yield of CO_2. The soluble material, which is readily oxidized and is independent of the suspended solids content, might account for this lack of correlation. Furthermore not all the constituents of the suspended solids are equally oxidizable and the relative proportion of these components may vary.

The CO_2 production on the basis of unit amount of suspended solids was lower from returned sludge than from sewage. The lowest yield of CO_2 from sewage was considerably higher than the highest yield

from returned sludge. This should be attributed to the oxidation of the organic matter during circulation of the sludge. In the same way

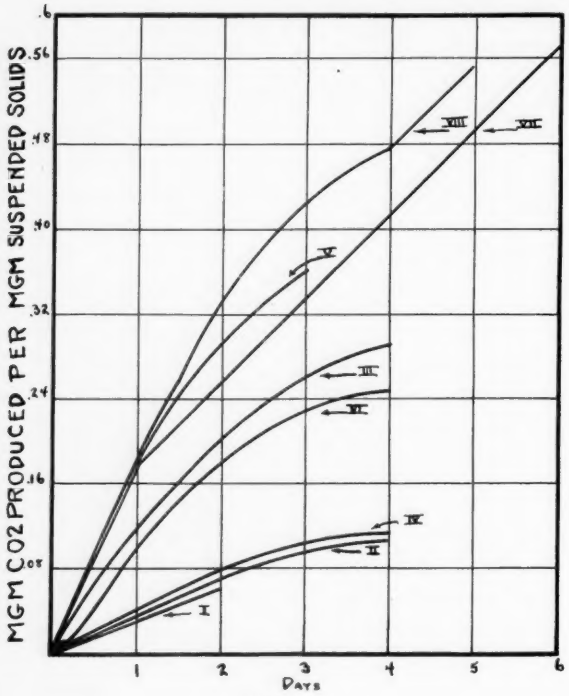

FIG. 5.

the differences in the various sludges should be explained on the basis of differences in the stage of oxidation.

CO_2 Production from Sewage and Sludge Mixtures as Compared with the CO_2 Production from Sewage and Sludge Alone

In Tables II and III are presented the differences in CO_2 production between the calculated and observed values for the various sludge and sewage mixtures in five series of experiments. The calculated results for the mixtures were derived from the CO_2 production rates of the sewage and sludge alone and the proportions of sewage and sludge in each mixture. Similar calculations for the remaining series could not be made because of lack of sufficient data.

In three of the series the observed results were consistently higher than the calculated results. The differences generally increased with the period of aeration as well as with increasing concentrations of suspended solids.

In Table III, however, are shown the results of two series which show higher calculated than observed results throughout the greater part of aeration. During the first six hours of the aeration period in

TABLE II.—*Difference in the CO_2 Production Between Observed and Calculated Values*

	Suspended Solids P.p.m.	Mgm. CO_2/L observed minus mgm. CO_2/L (calculated)				
		Hours				
		6	12	24	48	96
Series I	690	32.8	—	130.0	163.0	—
	1385	68.0	—	156.0	165.0	—
	2920	112.0	—	256.0	308.0	—
	5690	120.0	—	325.0	415.0	—
Series II	920	3.6	45	116	192	269
	1585	47	114	172	275	333
	3260	74	191	262	367	393
	5595	14	91	223	317	313
Series VI	450	0.3	9.9	38.0	92.5	183.0
	840	20.5	54.2	116.0	185.0	281.0
	1675	50.5	105.0	126.5	184.0	35.4
	2410	58.5	111.5	64.0	38.0	66.5

TABLE III.—*Difference in CO_2 Production Between Calculated and Observed Values*

	Suspended Solids P.p.m.	Mgm. CO_2/L calculated minus mgm. CO_2/L observed							
		Hours							
		6	12	24	48	72	96	120	144
Series VII	620	− 6.2	—	12.1	46.8	36.6	15.0	−9.9	20.8
	1020	−13.9	—	53.0	120.0	117.0	157.0	159.0	200.0
	1770	−9.5	—	24.2	81.0	73.5	29.6	64.5	110.0
	3020	−16.5	—	40.6	142.0	155.0	212.0	342.0	458.0
Series VIII	870	−24.9	−15.4	4.0	23.0	14.6	73.0	92.5	—
	1345	−34.8	−46.8	18.2	55.0	38.4	91.0	145.0	—
	2185	−52.0	−40.2	−20.8	111.0	146.0	260.0	246.0	—
	3360	−74.2	−66.0	−46.5	153	168.0	143.0	149.0	—

Series VII the observed results were somewhat higher than the calculated. Thereafter the relationship changed and the observed results were lower than calculated results. In Series VIII the shift took place after 12 hours and in the two higher concentrations in this series not until after 24 hours of aeration. Thereafter the differences again increased with time of aeration and with increasing concentration of sludge.

The results obtained at the London School of Hygiene, reported in the Water Pollution Research Board Report [6] are similar to those presented in Table II. In the English work the mixture of sewage and sludge absorbed oxygen at a higher rate than the sum of the amounts absorbed separately. The theory was advanced that the mixing of

sewage and activated sludge accelerated the rate of oxidation of either or both of the components. We have shown that in certain cases this is true and that the acceleration increases with increasing concentrations of sludge. In other cases a definite retardation seems to take place when sewage and sludge are mixed. By referring to Figure 5 it will be seen that those sludges which showed an acceleration of the rate of oxidation of the mixtures, produced less CO_2 when aerated than those that retarded the oxidation. It would seem plausible, therefore, that when a poorly oxidized sludge is mixed with sewage the oxidation of the mixture is retarded.

Discussion

In measuring the oxygen consumption of a material by any method we deal with three important factors, namely (1) the oxygen tension, (2) the flora and fauna, (3) the character and amount of the oxidizable material. The ideal situation in any method would be to keep the oxygen tension and the flora and fauna constant and to measure only the rate of oxidation and the amount of oxidizable material. Ordinarily this ideal is not attained. It has been generally accepted that the oxygen tension beyond a certain minimum is not an important factor. Results of some of our work on the effect of oxygen tension on bacterial members will be published in a subsequent paper. We have also assumed that the flora and fauna present in the material, as long as it is not disinfected or does not contain disinfectants, is sufficient to carry on the oxidation. It seems, however, that besides the total number of organisms, the type of flora and fauna is also important. Activated sludge, with its established aerobic flora, shows according to our results a more rapid rate of oxidation than fresh solids. Fresh solids, not being subjected to a process of stabilization, should contain a greater amount of oxidizable material. However, the rate of oxidation of this material as measured by the CO_2 production was lower than that of the activated sludge. By the B.O.D. method, on the other hand, the results with activated sludge and fresh solids were equal. It is possible that the initial low pH value of the fresh solids may have retarded the oxidation process by the aeration method while by the B.O.D. method this factor was not so important, due to the dilution with sodium bicarbonate water. The rate of CO_2 production from fresh solids during the first two days of aeration was lower than that from activated sludge. During this period, the pH value of the fresh solids increased from 5.4 to 6.6. However, in sewage which did not have a low pH value, the rate of CO_2 production was also lower than that in activated sludge. The evidence seems to indicate that in addition to other factors, such as pH, differences in the flora and fauna should be considered.

The results presented indicate that the CO_2 production measures significant differences in the rate of oxidation. It has been shown that the CO_2 production increases regularly with increasing concentration of sludge added to sewage, that different sewages and activated

sludge produce CO_2 at different rates even when the differences in the suspended solids concentration are taken into consideration. These variations in CO_2 production are probably caused either by differences in the character of suspended solids or by variations in materials not measured by the determination of suspended solids, such as colloidal and soluble materials. In the case of sewage both of these factors may be important but in the case of activated sludge the differences in CO_2 production are directly related to the stage of oxidation of the various sludges.

It will not be possible at present to use the CO_2 production as a basis for the computation of oxygen demand. Our CO_2 to B.O.D. ratios have generally been higher than 1.0. However, it is quite possible that had similar methods of aeration been used in both cases more consistent results might have been obtained. It does not seem fair to compare the rate of CO_2 production, with constant aeration and stirring, to the B.O.D. without such stirring, although presumably under similarly aerobic conditions. The aeration methods in comparison with the dilution method should prove of decided benefit by eliminating the variations in oxygen tension and possibly the zone of partial anaerobiosis in the liquid in contact with the sludge. The B.O.D. method, on the other hand, offers a solution to the problem of the effect of low pH values of the test materials when high dilutions are made with sodium bicarbonate or other buffered waters.

Direct comparisons of the results with those of other similar studies are difficult, not only because of differences in technique, but also because of differences in the type of materials used. Grant, Hurwitz and Mohlman [2] reported that oxygen consumption varied from 6.0 to 7.4 mgm. per gram of sludge per hour. Although most of our results are on the basis of longer periods, some results with 2-hour periods indicate CO_2 production of 2 to 4 mgm. per gram of sludge per hour. The rate of O_2 consumption obtained by these investigators is a straight line for the 2 to 4 hour period employed. Theriault and McNamee [7] obtained a straight line for the first 4 to 5 hours and a curve thereafter, the inflection of which decreased with increasing time. Some of the CO_2 results obtained in the present study with the various sludges can be readily represented by curves while others after several days of aeration change from a curve to a straight line.

Our results indicate that the greater the amount of sludge added to sewage the greater the CO_2 production. The increase in CO_2 production in some cases is more than can be accounted for by the CO_2 production of the sewage and sludge when aerated separately. A stimulating action of one component on the other, similar to those given in the Water Pollution Research Board Report,[6] is indicated by these results. On the other hand, we have also obtained lower CO_2 production in mixtures than would have been expected by the rates of CO_2 production of the sewage and the sludge alone. A retarding influence probably brought about by the addition of an additional load of sewage to poorly oxidized sludge would be indicated in this case.

Summary

Carbon dioxide production, commonly employed in biological and microbiological investigations to determine the rate of oxidation of organic materials, has been applied to determine the rate of oxidation of sewage, returned sludge and their various mixtures.

Comparisons were made of the rate of oxidation as measured by the CO_2 production and the B.O.D. methods. It was found that CO_2 production from sewage and activated sludge was higher than the oxygen consumption by the dilution method, resulting in CO_2 to B.O.D. ratios greater than unity. With fresh solids on the other hand ratios less than unity were obtained. Possible explanation for the failure of the ratio to approach unity have been advanced, based on differences in mixing and stirring. The differences in the ratios obtained from the sewage, activated sludge and fresh solids have been attributed to differences in their respective flora and fauna and the pH values.

Carbon dioxide production from eight different sewages (obtained from the same plant) and eight different returned sludges (all but one obtained from the same plant) have been presented. The rate of CO_2 production from the different sewages varied, even when expressed on the basis of suspended solids. Similarly, the CO_2 production from the returned sludges varied on the basis of suspended solids. The CO_2 production on the basis of suspended solids from the returned sludge was considerably lower than from sewage, so that there was no overlapping between the two types of materials.

When the sewage and returned sludge were mixed and aerated, the CO_2 values obtained were sometimes higher and at others lower than the expected results, calculated from the rate of CO_2 productions and quantities of each of the components. The differences appear to be related to the stage of oxidation of the sludge.

References

1. J. Burtle and A. M. Buswell, "A Comparison of Permanganate Oxygen Demand, B.O.D. and Direct Absorption of Oxygen," *Sew. Wks. Jr.*, **7**, 839 (Sept., 1935).
2. S. Grant, E. Hurwitz, and F. W. Mohlman, "The Oxygen Requirements of the Activated Sludge Process," *Sew. Wks. Jr.*, **2**, 228 (April, 1930).
3. H. Heukelekian, "Effect of Aeration on the Rate of Oxidation of Activated Sludge Mixtures," *Sew. Wks. Jr.*, **6**, 897 (Sept., 1934).
4. L. H. Kessler and M. S. Nichols, "Oxygen Utilization by Activated Sludge," *Sew. Wks. Jr.*, **7**, 810 (Sept., 1935).
5. Report of the Water Pollution Research Board including the Report of the Director of Water Pollution Research. H. M. Stationary office (1934).
6. *Ibid.*, 1935.
7. E. J. Theriault and P. D. McNamee, "Sludge Aeration Experiments. I. Rate of Disappearance of Oxygen in Sludge," *Ind. & Eng. Chem.*, **22**, 1330 (Dec., 1930).

THE USE OF CHLORINE FOR THE CORRECTION OF SLUDGE BULKING IN THE ACTIVATED SLUDGE PROCESS

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The efficiency of many activated sludge sewage treatment plants is materially affected at times by a diffuse or fluffy condition of the sludge particles, which, in the clarification tank following aeration, results in slow settlement and hence increased volume or "bulking" of the sludge. Consequently, in aggravated cases large amounts of these sludge solids may be carried over the effluent weirs instead of being removed through the bottom sludge outlets. Because this condition admittedly constitutes one of the "weak links" in this method of sewage treatment, our consultant, the late Mr. George W. Fuller, recommended the advisability of the Stream Pollution Investigations Station of the Public Health Service undertaking some studies of the biological and biochemical factors involved in sludge bulking.

Extensive microscopical observations of activated sludges have indicated that there are at least two distinct conditions of the sludge floc, either of which when present will cause the sludge to settle with difficulty, if at all. One is a thin, diffuse or spongy, ragged floc, that tends to float because of its relatively large surface area; the other is a floc possibly of moderate or good quality, but heavily infested with thin fungus threads which extend out in all directions from the main body and thereby increase greatly the buoyancy of the floc and doubtless separate materially the individual particles. All gradations and combinations of these two conditions may occur in specific instances. Thus a floc that is quite fine, ragged and diffuse may be settled in the final clarifier with reasonable success, but if a moderate growth of fungus should appear, the settling process is seriously retarded. The present discussion is confined to the bulking resulting from excessive amounts of fungus in the sludge.

For determination of the physical condition of sludge floc particles, the use of a low power (preferably binocular) microscope, magnifying about 20 or 30 diameters, is most essential. Daily routine observations of the sludge by such an instrument will disclose any progressive changes in floc structure that signify either the oncoming improvement or deterioration of sludge settling quality. By adjusting the substage mirror at a point slightly *in front* of the optical axis of the microscope to secure a dark field effect, and using a dilution (1 in 40 is suggested) of the sludge in a cell about 1 millimeter deep of the type used for plankton enumeration (with cover-glass adjusted) the floating flocs can be seen clearly outlined against a dark field and any attached fungus may be readily distinguished by reason of the light reflected from their

minute filaments, affording a sharp contrast with the surrounding dark field. A true picture of the undistorted floating floc, as it occurs in its natural environment in the clarification tank, is thus obtained.

References in the literature to bulking caused by fungus, including descriptions and characteristics of the causative organism, have been quite frequent. Many means have been suggested to inhibit the growth of the fungus such as the addition of lime, increased aeration, decreased aeration, chlorine, elimination of carbohydrates from the sewage to be treated, etc. One of the difficulties experienced in the use of chemicals for this purpose has been that when applied in a concentration sufficient to destroy the fungus growth, the normal fauna and flora essential for the functioning of activated sludge were killed and the effluent deteriorated rapidly.

Chlorine has been used in connection with the activated sludge process by many investigators. Dallyn and DeLaporte [1] in 1926 reported that return sludge was chlorinated to give a residual of 0.05 p.p.m. without upsetting plant operation. Apparently in this case the chlorine was used for odor control. In 1929, Bell [4] added bleaching powder to the return sludge at Barnsley, England, at an average rate of 22 p.p.m. available chlorine, and stated that it "has been found very useful in restricting the amount of septic matter returned to the aeration tank." Gascoigne [5] in 1931 reported the use in Canada of bleaching powder applied to return activated sludge to correct disturbances in the process. Heukelekian [6] in 1931 reported increased turbidity in the supernatant liquor due to sterilization of activated sludge with chlorine.

Chlorination of sewage entering activated sludge plants has been tried by many investigators with widely varying results. Goudey [7] in 1932 reported that, at Pasadena, prechlorination tended to cause bulking.

The Committee on Sewage Disposal of the American Public Health Association [10] reported in 1933 that "although chlorine has been tried by several investigators in an effort to control bulking of activated sludge, there are as many negative as positive results. Hence, its value for this purpose remains unproven."

Experimental Study.—Two methods of approach to the problem of fungus growth control seemed feasible. These were: (1) isolation of the organism in pure culture and determination of its growth requirements and possible elimination of essential foods or environmental conditions, and (2) addition of some material in a concentration toxic to the fungus but not to the other microscopic organisms normal to properly functioning activated sludge.

The first of these procedures has thus far not been successful. The fungus has been grown in pure culture, but our efforts to re-inoculate it into sewage have failed. Attention was, therefore, directed to the second method of control. Fungus laden, aerated sludge was treated, first in one-liter glass graduates and later in eight-liter bottles in which aeration was provided, with one of a number of toxic materials in varying amounts and these mixtures examined under the microscope

after definite intervals of time to observe the effect of the chemicals on the fungus strands, as well as upon the other forms of plankton. Phenol, lime, copper sulphate, iron salts, alum, sulphur, silica gel, activated carbon, sodium sulphite and chlorine were among the chemicals employed. The most consistently favorable results were obtained with chlorine, which, if added in proper proportion, appeared to shrivel the protruding strands of fungus but did not destroy the normal plankton associated with the sludge floc.

Based on these observations, tests were continued on a larger scale in the experimental activated sludge treatment plant when bulking of sludge was experienced. This unit had been operated for several days prior to August 28, 1934, on the fill-and-draw method. The sludge was in such condition that, after 90 minutes settling, the sludge blanket was only 3 inches below the surface and fungus growths in the floc particles were very abundant. On that date chlorine to the amount of 22.5 p.p.m. was added to the sludge-sewage mixture in the aeration tank and after an interval of 1½ hours standing, observations indicated that the fungus was adversely affected but that other plankton—except stalked ciliates—remained active. After re-seeding with sewage-sludge liquor from another unit to the extent of 4 per cent of the tank volume, operation was resumed. The sludge index—$\frac{\text{suspended solids in p.p.m.}}{\text{settlable solids in c.c. per liter}}$—increased from 2.1 to 10.4 by this treatment and continued to improve, reaching 16.3 by September 10, 1934.

Following these favorable results the suggestion was made to Mr. E. E. Smith in charge of the Lima, Ohio, activated sludge plant that the application of chlorine might be of value in retarding the growth of fungus in the activated sludge and thereby improve the bulking condition being experienced. Favorable results were obtained, as recorded by Mr. Smith [12] and chlorination has since constituted an integral part of the treatment at that plant. Mr. Smith, however, made one noted change in the treatment in that he introduced the chlorine into the return sludge and in smaller amounts than had been attempted before.

During the past year chlorine has been frequently used to reduce fungus growths in activated sludge at this station, using Mr. Smith's method of applying small amounts to the return sludge. Results, in so far as fungus control is concerned, were uniformly successful. An improvement in the settling of the floc was always obtained if fungus was present, but if the bulking of the sludge was due in any great degree to the presence of a light, diffuse floc, the improvement was not always sufficient to insure satisfactory operation of the plant. Observations pertinent to these experiments are given in Table I, which lists the conditions at the start, the average amount of chlorine used and its effect as shown by the sludge condition at the end of the experiment.

These results plainly show that chlorine applied in small amounts to the return sludge reduced fungus growths and so effected an im-

TABLE I.—*Experiments Showing the Effect of Chlorine in Control of Sludge Bulking Resulting from Fungus Laden Sludge Floc*

Exp. No.	Date	Aver. Amount Chlorine Used		Sludge Index	Sludge Blanket Per Cent of Sett. Tank Water Depth	Effluent Susp. Solids P.p.m.	Amount Fungus Present	Floc Condition
		P.p.m. Ret. Sludge	Perct. of Ret. Sludge Dry Solids					
1	12/ 3/34	3.46		4.3	100	149	Moderate	Ameboid, ragged
	12/ 9/34	0		5.3	89	128	Small	Ragged
	12/17/34			8.8	99	170	Small	Ragged
2	12/17/34	1.52		8.8	99	170	Small	Ragged
	1/ 7/35	0		10.1	14	18	0	Granular, ameboid
	1/29/35			5.6	95	172	Trace	Ragged
3	3/27/35	1.37	.04	1.8	100	312	Mod. abund.	Spongy, ragged
	5/14/35			2.4	39	10	Small	Spongy, ragged
4	6/ 6/35	2.12	.04	1.8	79	108	Mod. abund.	Ragged
	6/17/35			2.6	17	26	Small	Spongy, ragged
5	6/24/35	1.68	.03	4.9	Less than 13	12	0 to trace	Ameboid
	7/17/35			5.1	Less than 13	8	Trace	Spongy, ragged
6	9/21/35	.467	.007	3.8	90	26	Large	Large, ragged, dense
	10/15/35	0	0	10.0	26	12	Moderate	Large, ragged, dense
	10/25/35			5.0	84	57	Large	Large, ragged, dense
7	10/26/35	.620	.008	5.4	78	29	Large	Large, ragged, dense
	11/ 5/35			13.9	13	8	Moderate	Large, ameboid

provement in the sludge. Except in Experiment 5 there was a noticeable improvement in the settling of the sludge in the final clarifier, the sludge blanket level dropped, the effluent improved and the sludge index rose. Experiments 1, 2, and 6 indicate clearly how plant operation improved with the use of chlorine and how, with cessation of chlorination, after an interval bulking again recurred with attendant operating difficulties. Experiments 1 to 5 inclusive also show clearly that al-

though chlorine reduced the interference with proper settling caused by fungus filaments, this treatment did not cause the floc particles to coagulate and did not aid in controlling the bulking that is due to small, light floc particles of comparatively low specific gravity.

Experiments 6 and 7 were made with intermittent, instead of continuous, chlorination of the return sludge. The chlorine dosages were much lighter than in the other experiments, but were apparently effective in destroying the fungus filaments. These two experiments show the remarkable improvement in sludge settling due to the action of chlorine on fungus filaments attached to large, dense flocs. Experiment 6 also shows the rapid decrease in settling rate of the sludge due to increased fungus growth when chlorination was suspended.

Tables II and III give daily results for Experiments 4 and 6 respectively. It is interesting to note that in Experiment 4 when the chlorine dosage was about 2.5 p.p.m. or .05 per cent on a dry solids basis, the sludge settling improved, but when the dosage dropped to 1.7 p.p.m. or less (about .03 per cent of the dry solids) the settling deteriorated. In Experiment 6, however, chlorine in the amount of 0.7 p.p.m. or .01 per cent of the dry solids was ample to effect a marked improvement in the settling. The difference may be due to the marked dissimilarity in the two flocs.

TABLE II.—*Detailed Observations of Chlorine Treatment of Bulking Sludge. Experiment No. 4*

Date	Chlorine Used		Sludge Index	Sludge Blanket Per Cent of Sett. Tank Water Depth	Effluent Susp. Solids P.p.m.	Amount Fungus Present
	P.p.m. Return Sludge	Per Cent of Return Sludge Dry Solids				
June 6, 1935	2.02	.04	1.8	79	108	Mod. abund
7	2.73	.06	1.6	67	34	" "
8	2.73	.05	1.9	53	10	" "
9	2.59	.05	2.5	44	10	——
10	2.74	.05	2.1	40	4	Mod. abund.
11	2.57	.04	2.8	40	5	" "
12	1.60	.03	2.4	82	18	Small
13	1.70	.03	2.6	91	120	"
14	1.60	.03	2.5	92	92	Moderate
15	1.80	.03	3.3	60	28	"
16	1.79	.03	3.0	13	28	——
17	1.60	.03	2.6	17	26	Small

Note: After June 15th, not enough sewage to supply plant. Trouble in street sewer.

In November, 1935, an opportunity was provided to test the use of chlorine for reduction of fungus growths in routine plant operation. The City of Lancaster, Pa., had experienced much trouble with bulking activated sludge at its South Plant and requested aid in solving the problem from the U. S. Public Health Service. After investigation of

TABLE III.—*Detailed Observations of Chlorine Treatment of Bulking Sludge. Experiment No. 6*

Date	Chlorine Used		Sludge Index	Sludge Blanket Per Cent of Sett. Tank Water Depth	Effluent Susp. Solids P.p.m.	Amount Fungus Present
	P.p.m. Return Sludge	Per Cent of Return Sludge Dry Solids				
Sept. 21, 1935	0.419	.0078	3.8	90	26	
22	.419	.0078	—	94	26	
23	.419	.0077	4.3	74	31	
24	.419	.0076	4.2	73	17	
25	.419	.0070	4.6	73	17	
26	.429	.0083	4.6	70	15	
27	.429	.0067	—	63	29	
28	.402	.0060	6.0	48	15	
29	.402	.0060	—	52	15	
30	.402	.0067	6.0	47	11	
Oct. 1, 1935	.402	.0068	4.7	50	17	Noticeable decrease
2	.402	.0062	6.1	54	13	
3	.402	.0054	6.1	57	19	Large
4	.402	.0057	6.3	51	12	
5	.402	.0042	6.6	58	18	
6	.402	.0042	—	42	18	
7	.402	.0055	7.0	68	21	Moderate
8	.402	.0057	6.1	85	46	"
9	.618	.0095	4.4	90	49	"
10	.690	.0112	5.4	50	15	"
11	.690	.0106	5.7	57	16	"
12	.690	.0098	6.4	48	17	Abundant
13	.690	.0098	—	34	17	——
14	.690	.0123	8.6	26	11	——
15	.690	.0099	10.0	15	12	Moderate
16	0	0	10.4	15	13	Mod. abund.
17	0	0	10.2	50	15	——
18	0	0	11.6	25	12	Small
19	0	0	10.6	34	13	Mod. abund.
20	0	0	—	38	13	——
21	0	0	8.7	35	11	——
22	0	0	9.4	25	11	Mod. abund.
23	0	0	8.5	31	13	" "
24	0	0	—	59	16	Large
25	0	0	5.0	85	57	"

plant arrangement and conditions, the trial use of chlorine was recommended. The floc was large, very diffuse and apparently loosely bound together with fungus filaments, which were present in large amount. Although it was realized that chlorine would not overcome the diffuseness of the floc, it was felt that reduction in the amount of fungus would cause some improvement in the settling of the sludge. The return sludge was chlorinated for four days (Nov. 22 to Nov. 26) at the rate of 4.57 p.p.m. or 0.11 per cent of the dry solids. When chlorination

was stopped, the amount of fungus had been greatly reduced and the stalked ciliates, chiefly epistylis, were beginning to show the effect of the chlorine. During the chlorination of the sludge an unexpected, interesting increase of turbidity of the effluent occurred. The chlorine apparently destroyed some of the fungus strands that had previously loosely held the floc material together. The average size of the floc decreased and considerable very fine floc material, much of it nearly colloidal, appeared in the effluent. Before chlorination was stopped, much of this loosened material had washed out of the floc and the effluent was beginning to clear. After chlorination was stopped, the turbidity continued to decrease.

Since November 26, 1935, chlorine has been used regularly, but in smaller amounts, to prevent excessive growths of fungus. At the end of the year, December 31, 1935, the treatment has continued successful, the sludge is settling reasonably well, and the final effluent contains about 10 p.p.m. suspended solids.

Conclusions

Frequent, periodic examination of the sludge floc in a cell under a low power microscope is essential to obtain proper information concerning the condition of the sludge floc in its natural environment.

Bulking of activated sludge may be caused by diffuse floc structure, fungus growth or combinations of both.

Chlorination of the return sludge at low rates is a useful method for combating bulking due primarily to fungus growth. Results indicate that the proper rate of chlorination lies between 0.7 and 7.0 p.p.m., based on return sludge, or .01 per cent and 0.1 per cent based on the weight of dry solids, depending upon the character of the sludge floc.

Chlorination is not successful against that type of bulking due to light, diffuse floc.

Chlorination of an activated sludge is attended by the serious danger of overchlorinating and destroying the desirable plankton growths. The margin of safety is small and use of the method requires constant, careful supervision.

References

1. F. A. Dallyn and A. V. DeLaporte, "Recent Research in Sewage Disposal," *Canadian Engineer,* **50,** 213–15 (February 9, 1926).
2. E. H. Morgan and A. J. Beck, "Carbohydrate Wastes Stimulate Growth of Undesirable Filamentous Organisms in Activated Sludge," *Sewage Works Journal,* **1,** 46–51 (October, 1928).
3. C. C. Ruchhoft and J. H. Watkins, "Bacteriological Isolation and Study of the Filamentous Organisms in the Activated Sludge of the Des Plaines River Sewage Treatment Works," *Sewage Works Journal,* **1,** 52–58 (October, 1928).
4. H. D. Bell, "The Application of Bleaching Powder as an Auxiliary Treatment of Sewage," *Proceedings of the Association of Managers of Sewage Disposal Works,* 1929, pp. 175–203.
5. George B. Gascoigne, "Chlorination of Sewage and Sewage Effluents," *Sewage Works Journal,* **3,** 38–49 (January, 1931).

6. H. Heukelekian, "Partial and Complete Sterilization of Activated Sludge and the Effect on Purification," *Sewage Works Journal*, 3, 369 (July, 1931).
7. R. F. Goudey, "The Increased Use of Chlorine in Sewage Treatment," *Municipal Sanitation*, 3, 10–14 (January, 1932).
8. T. R. Haseltine, "The Activated Sludge Process at Salinas, California, with Particular Reference to Causes and Control of Bulking," *Sewage Works Journal*, 4, 461–89 (May, 1932).
9. Jan Smit, "A Study of Conditions Favoring Bulking of Activated Sludge," *Sewage Works Journal*, 4, 960–72 (November, 1932).
10. "Chlorination in Sewage Treatment." Report of Committee on Sewage Disposal. American Public Health Association. October, 1933.
11. Jan Smit, "Bulking of Activated Sludge. II. On the Causative Organisms," *Sewage Works Journal*, 6, 1041–52 (November, 1934).
12. E. E. Smith, "Experience with Chlorination of Activated Sludge," *Water Works and Sewerage*, 82, 362–64 (October, 1935).

Plant Operation

EXPERIENCES WITH CHEMICAL TREATMENT OF SEWAGE AT BIRMINGHAM, ALABAMA *

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Introduction

The Shades Valley Sewage Treatment Plant at Birmingham, Alabama, is of the chemical precipitation type, having a capacity of 2 million gallons per day for complete chemical treatment during the dry season and 4 m.g.d. for primary treatment during the winter months. The plant (Figs. 1 and 2) has been in operation since the late summer of 1934.

Fig. 1.—Shades Valley Sewage Treatment Plant. Settling tanks in foreground.

A complete description of the design and initial operation has been published (1), also a description of the unusual design problems encountered in both the drainage area and the receiving stream, the solution of which led to the selection of a chemical precipitation type of plant for seasonal treatment (2). This paper is therefore limited to a discussion of the operating results, costs, and difficulties encountered at this plant from January 1 to December 31, 1935, together with the results of experimental work on the chemical precipitation of sewage conducted in the central laboratory at the Ensley Plant.

Operating Results

The plant was operated as a chemical precipitation plant for complete treatment from June 15 to November 11, 1935 and as a sedimentation plant for primary treatment during the remainder of the calendar year.

* Presented before the Eighth Annual Meeting of the New York State Sewage Works Association, New York City, January 14, 1936.

A total of 615 million gallons of sewage passed through the plant during the year, of which 522 m.g. was during the winter season when chemicals were not added, giving an average flow during the wet season

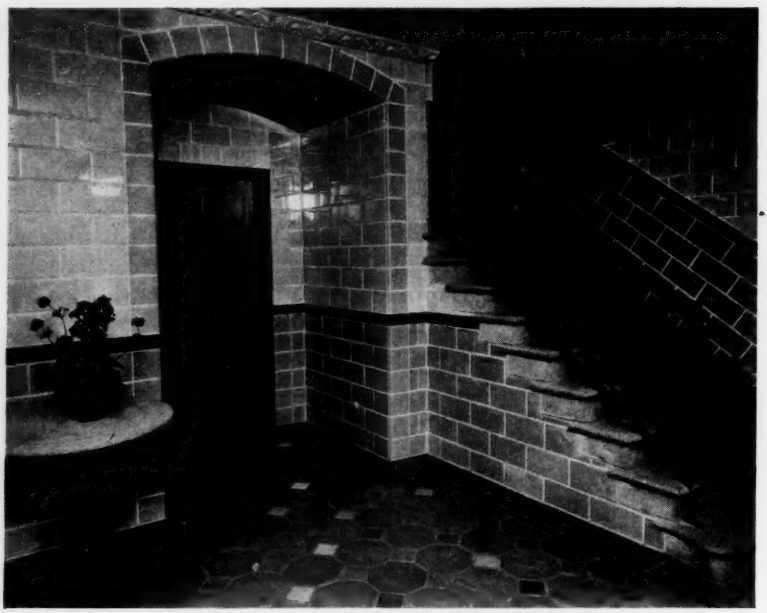


FIG. 2.—Entrance lobby, Shades Valley Plant.

of 2.4 m.g.d. The total flow from June 15 to November 11, 1935, when chemicals were added, was 92.6 m.g. giving an average flow of 0.62 m.g.d. The maximum rate of flow was 5.2 and the minimum rate 0.3 m.g.d. Only that period during which the plant was operated as a chemical precipiation unit will be discussed here.

The suspended solids content of the raw sewage averaged 124 parts per million with a maximum of 590 p.p.m., which was reduced to an average of 10 p.p.m. in the final effluent, a reduction of 92 per cent.

The average B.O.D. of the raw sewage was 85 and the maximum 185 p.p.m. This was reduced to an average of 12 p.p.m. in the final effluent, a reduction of 86 per cent.

The dissolved oxygen in the raw sewage averaged 0.1 p.p.m., being zero the majority of the time. This was increased to an average of 2.8 p.p.m. in the effluent. We attribute this increase to the mixing action in the flash mixer and flocculator.

The average pH of the raw sewage was 7.1 and that of the effluent 6.8.

The turbidity was decreased from an average of 250 in the raw sewage to an average of 6 p.p.m. in the effluent.

The total iron content of the raw sewage averaged 2.6 p.p.m. which was decreased to 1.7 p.p.m. in the effluent. Practically all of the iron

in the raw sewage is removed by sedimentation; by reacting with the excess chlorine added, the iron forms ferric chloride which is precipitated as ferric hydroxide, a pin-point floc that does not settle. (See Table I.)

TABLE I.—*Shades Valley Plant Operating Results, June 15 to Nov. 11, 1935*

	Raw Sewage			Effluent			% Removal
	Max.	Min.	Av.	Max.	Min.	Av.	
Sewage Flow, m.g.d.	5.2	.30	.62				
Suspended Solids, p.p.m.	592	40	124	22	3	10	92
B.O.D., p.p.m.	195	35	85.5	20	3	12	86
Dissolved Oxygen, p.p.m.	.9	.0	.1	3.7	1.8	2.8	—
pH	7.3	6.9	7.1	6.9	6.6	6.8	—
Turbidity, p.p.m.	1000	70	150	15	3	6	96
Total Iron, p.p.m.	12	1.0	2.6	5.5	0.1	1.7	35
Dissolved Iron, p.p.m.	.8	.1	.3	.3	.0	.1	66

The above results were accomplished by the addition of a total of 44,430 lb. ferrous sulphate ($FeSO_4$ 7 H_2O) and 6,450 lb. chlorine. This does not include the chlorine added for odor control but does include approximately 1.0 p.p.m. excess chlorine as a factor of safety against incomplete chlorination of copperas. This gives an average of 480 lb. copperas and 70 lb. chlorine per million gallons of sewage treated, which is equivalent to 11.5 p.p.m. of metallic iron. (See Table II.)

TABLE II.—*Shades Valley Plant, Chemicals Added June 15 to Nov. 11, 1935*

Chemicals	Per Day			Per m.g.		
	Max.	Min.	Av.	Max. Rate	Min. Rate	Av. Rate
Pounds Ferrous Sulphate ($FeSO_4 \cdot 7H_2O$) Added	485	210	296	960	180	480
Pounds Chlorine Added	70	30	42	137	25	70
Cost Dollars						5.70

Copperas at ¾ cent per pound
Chlorine at 3 cents per pound

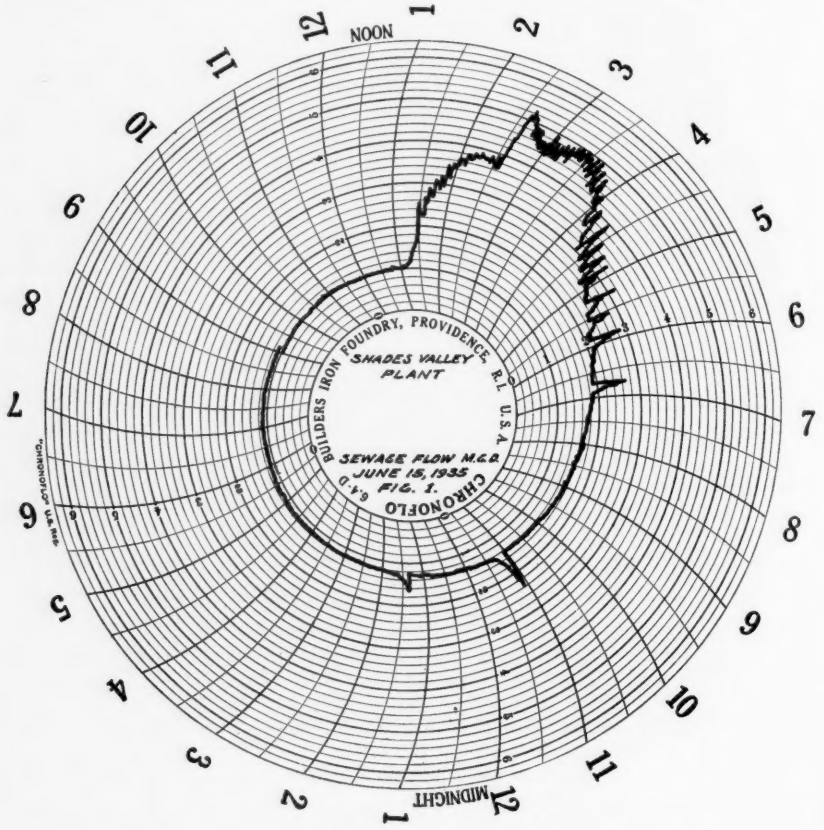
The copperas added varied from a maximum rate of 960 to a minimum rate of 180 lb. per m.g. This wide variation in the amount of coagulant required was caused by several factors, the most important of which are as follows:

1. The outfall sewer coming into the plant is a 42-inch diameter conduit laid on a slope of 0.08 per cent. During the dry weather, solids are deposited in this sewer and are then flushed down to the plant by the first rain. The suspended solids content has increased from 137 p.p.m. one day to 592 p.p.m. the next day, and at the same time the volume of sewage has increased. (See Table III.)

TABLE III.—*Showing Variation in Strength of Sewage Caused by Flushing of Outfall Sewer 24 Hour Composite Samples*

Date	Flow m.g.d.			Total Solids p.p.m.	Susp. Solids p.p.m.
	Max. Rate	Min. Rate	Total		
Aug. 11, 1935	0.75	0.38	0.61	418	137
Aug. 12, 1935	1.40	0.38	0.73	814	592
Aug. 13, 1935	0.78	0.38	0.63	360	117

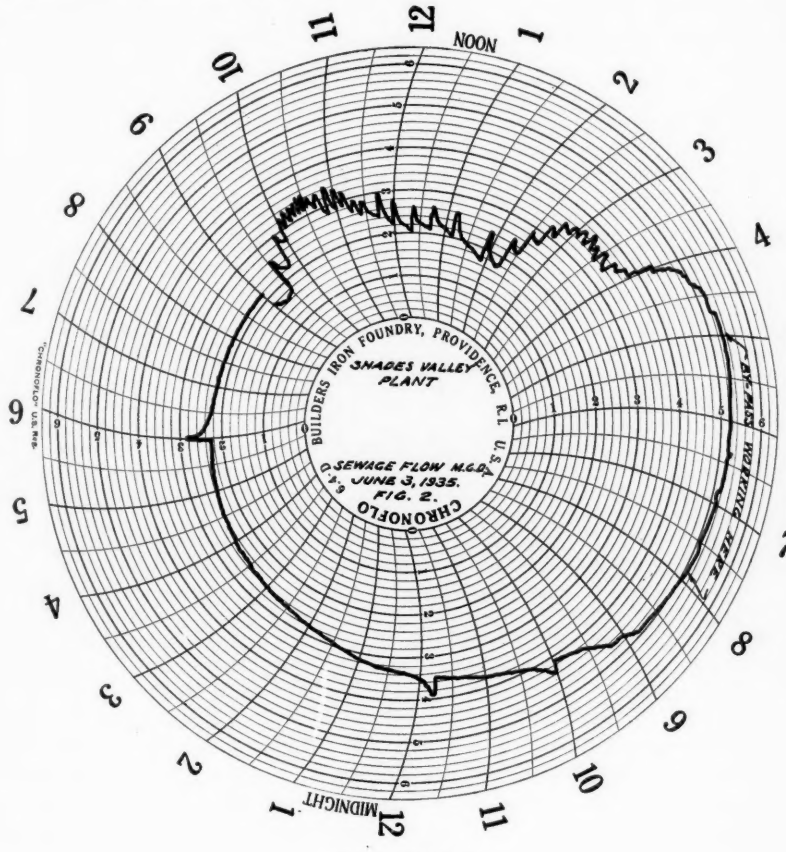
2. The collecting system tributary to the plant is in a large undeveloped area, therefore the ratio of ground water to sewage is unusually high during wet weather. The rate of sewage flow has increased from 1 to 5 m.g.d. in less than two hours (see flow charts A and B).



FLOW CHART A.

3. There is unusual variation in the strength and volume of sewage during a 24-hour period. The Shades Valley Plant seems to be worse

than an Atlanta Plant, in which Killam (3) found that 97.5 per cent of the load, expressed in flow and suspended solids content, arrived during 16 hours of the day.



Flow Chart B.

In the routine operation of the Shades Valley Plant the dosage of chemicals is changed eight times daily. These changes are based on flocculation tests in the laboratory, observation of the sewage and the past experience of the operator.

Operating Costs

The total cost for the year 1935, exclusive of fixed charges, was $7,533.64, which may be broken down as follows:

Power $1,802.24; Paint, Oil and Grease, Laboratory Supplies, Repairs, Maintenance and Supplies $524.65; Salaries $4,680.00; Chemicals $526.75. This makes the average cost for the entire year $12.25 per m.g. sewage treated or $11.39 per m.g. for the winter season, when the plant was operating as a primary plant only and $17.10 per m.g. for

the summer months, when complete chemical treatment was given. With chlorine at 3 cents per pound and copperas at ¾ cent, the chemical cost was $5.70 per m.g. These costs are based on the actual volume of sewage treated, which was less than one-half design capacity. Furthermore, the cost of chemicals in Birmingham is relatively high. (See Table IV.)

TABLE IV.—*Operating Cost Shades Valley Plant, Jan. 1 to Dec. 31, 1935*

Item		Cost	
Power, 49,300 k.w.h.		$1,802.24	
Paint		22.81	
Oil and Grease		47.29	
Maintenance and Supplies		181.63	
Laboratory Supplies		204.21	
Repairs		68.71	
Total		$2,326.89	
2 Operators,	12 Mos. @ 200.00	$2,400.00	
2 Asst. Operators,	12 Mos. @ 150.00	1,800.00	
1 Janitor,	12 Mos. @ 40.00	480.00	
Total Labor		$4,680.00	
Total Labor and Material			$7,006.89
Chlorine, 6450 lbs. @ $.03		$ 193.50	
Ferrous Sulphate, 44,430 lbs. @ $.0075		333.25	
Chemical Cost		$ 526.75	
Total Operating Cost			$7,533.64

OPERATING EXPERIENCES

The operation and chemical control of this plant has been much simpler and easier than was anticipated. The amount of chemical required has been less than was expected from preliminary studies made before the plant was designed. The average amount of iron added was approximately 11 p.p.m., while the preliminary estimates were 15 p.p.m.

The copperas is very easy to handle and after practically two seasons of operation we have less than 50 pounds of lumps or impurities that have accumulated. Both the chlorine and copperas feed lines are 1½-inch rubber hose. It is necessary to flush out the copperas line weekly and to take it out and clean it about every two months. The plant is equipped with duplicate feed lines, making this cleaning operation very simple.

As the digesters in this plant were designed for approximately three times the present connected population any detail data that might be given on the digestion of chemical sludge would be misleading.

DIGESTER OVERFLOW

The Shades Valley Plant has a two-stage digestion system, the primary tank being heated and equipped with a stirring mechanism, while

the secondary unit is a plain unheated tank. All of the supernatant overflow is taken off near the top of the secondary tank.

This supernatant overflow has an average B.O.D. of less than 100 and a suspended solids content of 200 p.p.m. The supernatant overflow from single-stage digesters in the district have approximately seven times this suspended solids content. (See Table V.)

TABLE V.—*Comparison of Digester Overflow Liquor, Shades Valley Plant and Ensley Plant* Shades Valley*

	Max.	Min.	Av.
Total Solids p.p.m.	1100	750	887
Suspended Solids p.p.m.	356	46	204
B.O.D.	177	19	64
pH	7.1	6.9	7.0

Ensley

	Max.	Min.	Av.
Total Solids p.p.m.	4040	1510	2699
Suspended Solids p.p.m.	2860	488	1506
B.O.D.	705	70	341
pH	7.5	6.9	7.2

* Shades Valley plant has two-stage digestion system. Ensley plant has single-stage digestion.

This digester overflow contains approximately 200 p.p.m. total iron of which 175 p.p.m. is in the ferrous state. If sufficient chlorine is added to change this ferrous iron back to the ferric state it will precipitate, carrying practically all the suspended solids with it, leaving a sparkling clear supernatant overflow with a B.O.D. and suspended solids content of less than 10 p.p.m. If this soluble ferrous iron is not changed to the ferric state, and the sewage arriving at the plant is strong and stale, the iron will react with the hydrogen sulphide present forming ferrous sulphide, giving a distinct color in the primary settling tank. This color is from gray to black depending upon the strength of the sewage. That part of the ferrous iron that does not react with hydrogen sulphide and which is not changed to the ferric state will be carried out in the plant effluent.

Laboratory Work

In an effort to improve the plant operation and to determine some of the factors involved in the chemical precipitation of sewage, extensive small-scale studies were made in the central laboratory at the Ensley Plant and the results were applied or tried out in the Shades Valley Plant. To date these studies have included pH control, preliminary sedimentation, returned sludge, sludge concentration and others.

pH Control.—In order to find the most economical point on the pH scale for the coagulation of the Shades Valley sewage, a laboratory study was made as follows:

Sufficient chlorinated copperas was added to the raw sewage to coagulate it, giving a clear supernatant liquor without adjusting the pH from 7.2. The amount of coagulant required at this pH was determined and called 100 per cent. Then lime was added until the pH was adjusted by degrees to a pH of 11.0 and the amount of iron required for complete coagulation at these points was determined by flocculation tests. Then sulphuric acid was added until the pH was adjusted by degrees down to a pH of 4.0, and the amount of iron required for complete coagulation at these various points was determined by flocculation tests.

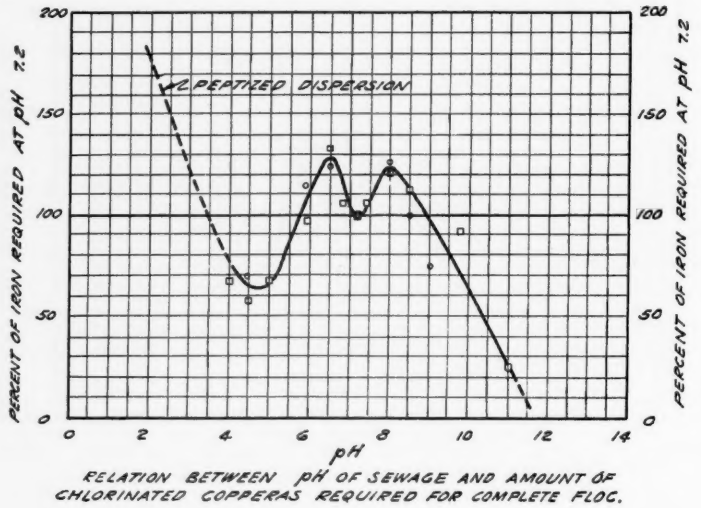


FIG. 3.

According to these studies, the cost of chemicals required for complete clarification at a pH of 7.2 was approximately one-half the cost at a pH of 9.0 and one-fourth the cost at a pH of 4.0. (See Figure 3 and Table VI.)

TABLE VI.—*Reagents Needed to Produce Desired pH Shown in Fig. 3.*

pH	Reagent Added	Pounds Per m.g.
4.0	H_2SO_4	2210
5.0	H_2SO_4	1710
5.9	H_2SO_4	1460
6.5	H_2SO_4	625
6.9	H_2SO_4	250
7.2	None	0
8.0	Lime	420
8.5	Lime	625
9.0	Lime	1250
9.7	Lime	2500
11	Lime	3750

Even though pH control could be economically justified, it would require a second adjustment of reaction to neutralize the alkalinity or acidity before the effluent could be discharged. Also the control of the pH is a delicate procedure, as the amount of acid or lime required will vary with the amount of alkalinity, acidity and buffering action of the sewage. Our studies were made on a highly buffered sewage and the conclusions would not necessarily apply at other places. For these reasons the Shades Valley Plant is operated as a straight iron precipitation plant without pH control.

It is interesting to note that at a pH of 6.5 and 8.0 the amount of iron required for coagulation was greater than that required at a pH of 7.2 without adjustment. Below a pH of 4.0 the colloidal solids were peptized into a stable dispersion. On the alkaline side, when sufficient lime was added, a straight lime precipitation resulted at a pH above 10.0.

Pre-Settling.—In a previous paper (1), the writer stated:

"Although the period of operation to date has been too short to give conclusive results, the following indicates in a general way what may be expected—A test run was made to determine the effect of pre-sedimentation. To obtain substantially the same results it was necessary to add 15 parts per million more chlorinated copperas than when preliminary sedimentation was not used."

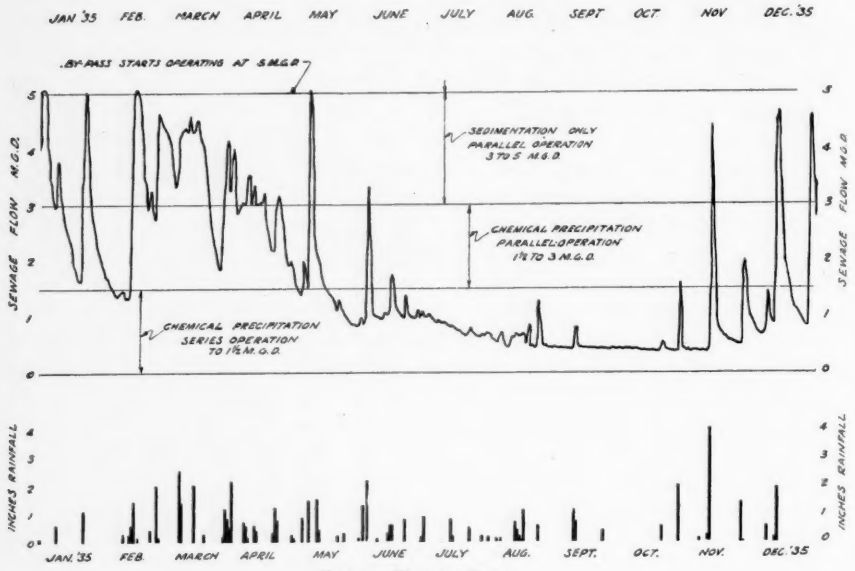
Additional information collected over a longer period of time shows that in the previous test run a change in the strength of sewage was the probable cause of the greater amount of chemicals required with unsettled sewage, rather than a saving due to the removal of settleable solids. In hundreds of laboratory determinations we were unable to find any difference in the flocculating or coagulating properties of settled and raw sewage. In fact, the writer is familiar with one case where settled sewage required considerably more coagulant than the raw sewage.

Although the removal of settleable solids from the sewage may not decrease the amount of coagulant required, pre-sedimentation has a place in a chemical precipitation plant, for the following reasons.

In most cases where chemical precipitation is installed for seasonal treatment, if sufficient settling tank capacity is provided for the average flow during the winter season, there will be plenty of settling space for pre-settling during the summer season, when the sewage is stronger and the problem of disposal is more acute. Pre-settling is therefore simply a more efficient arrangement of the total settling capacity. This is the case at the Shades Valley Plant, which is operated as a 1.5 m.g.d. chemical precipitation plant with pre-sedimentation (series operation) in the dry, hot season, and a 3.0 m.g.d. sedimentation plant (parallel operation) in the wet, cold season. (Fig. 4.)

As noted above, the present average flow during the summer months was 0.6 m.g.d. while during the winter months it was 2.4 m.g.d. The plant was designed on the basis of a detention period of 1.0 hr. with a flow of 2 m.g.d. in each of the settling tanks. On this basis the capacity

in series operation would be 2 m.g.d. We have found that the detention period of one hour in the final settling tank is not sufficient, therefore, the plant is changed to parallel operation when the flow is greater than 1.5 m.g.d.



SHADES VALLEY PLANT.
SEWAGE FLOW AND RAINFALL.
FIG. 4.

Other advantages of pre-settling are that it tends to smooth out variations in the strength and volume of sewage before the chemicals are applied, and it also gives the operating force more time to make flocculation tests before the sewage reaches the mixing chamber.

None of these observations are meant to apply to pre-settling when the chemical sludge from the final settling tank is pumped back to the raw sewage before it enters the primary settling tank. In fact, another advantage of preliminary sedimentation is that it makes possible the return of chemical sludge to the raw sewage and its removal by settling before additional chemicals are added.

Return Sludge.—At the Shades Valley Plant the preferred method of operation is series operation with return of chemical sludge to the raw sewage. This return of chemical sludge to the raw sewage is very effective for odor control, in that the iron combines with any hydrogen sulphide present to form the non-volatile iron sulphide, without the medicinal odors usually characteristic of pre-chlorination. The enormous colloidal surfaces and capillary pores of the return sludge floc enable it to adsorb additional sewage solids as it settles. This adsorption action is increased by a short period of mechanical stirring before sedimentation. Any un-neutralized positive charge caused by slight

overdosage of chemicals is brought in contact with excess of negatively charged sewage particles, assuring complete utilization of the coagulant.

The return of chemical sludge gives a uniform mixture of sludges entering the primary digester, with a higher solids content than can be obtained when the sludges are added separately.

Returning the chemical sludge to the incoming sewage lowers the acidity of the sludge. The average pH of the chemical sludge was 6.7, while that of the mixed sludge was 7.1.

In the treatment of sewage with a ferric iron salt as the coagulant, the ferric ions tend to be reduced to ferrous ions, due to the presence of hydrogen sulphide and other reducing compounds. This reduction will also take place with the hydrous oxide floc in the returned chemical sludge. One part of hydrogen sulphide will combine with 1.65 parts iron to form iron sulphide. It is therefore apparent that in the chemical treatment of sewage with an iron salt it is essential that the sewage be kept fresh while in contact with the chemical sludge, either by dissolved oxygen, chlorine, or by aeration.

In returning chemical sludge to the raw sewage, care must be exercised to prevent this reduction of the hydrous oxide floc to a soluble ferrous salt by the hydrogen sulphide and the organic matter present in the sewage and entrapped in the sludge particles. These ferrous salts often become re-oxidized either by exposure to the atmosphere or by the dissolved oxygen in the sewage, and, when additional chemicals are added, form an insoluble peptized dispersion, thus giving an iron color to the final effluent.

In order to prevent this reduction of the return sludge, a small amount of free chlorine is carried throughout the process in the Shades Valley Plant. The reduction of the iron in the returned chemical sludge is easily prevented by free chlorine, or air, when the fresh sludge is returned continuously at the same rate at which it is collected, and immediately allowed to settle in a preliminary settling tank. However, in re-circulation of chemical sludge as a continuous process in which some of the sludge might be in circulation for a considerable period of time, the prevention of reduction by air or chlorine will probably be impractical.

Some experimental work was carried on in the Ensley laboratory in which measured volumes of chemically precipitated sludges were mechanically mixed with settled sewage for fifteen minutes and then settled for one hour. This work indicated that the addition of 5 per cent by volume of chemical sludge reduced the turbidity from 160 to 60 p.p.m. (Fig. 5), the suspended solids from 125 to 60 p.p.m. (Fig. 6) and the B.O.D. from 250 to 165 p.p.m. (Fig. 7).

This work indicates that considerable non-settleable solids may be removed by the return of the chemical sludge to a stirring device where it is mixed with the raw sewage and thence flows to a preliminary settling tank for pre-sedimentation before additional chemicals are added.

Sludge Concentration.—A sample of chemically precipitated sludge was allowed to stand for approximately fifteen hours; the solids content increased from 1 to 2.5 per cent, giving a decrease in volume of 60 per

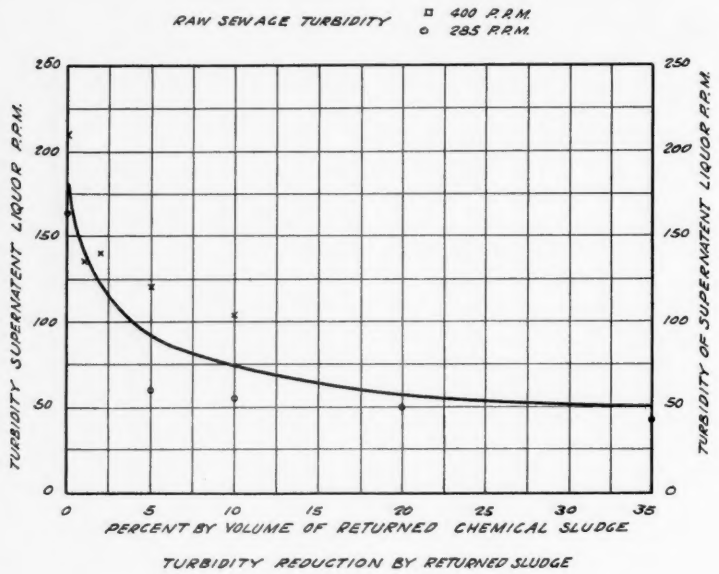


FIG. 5.

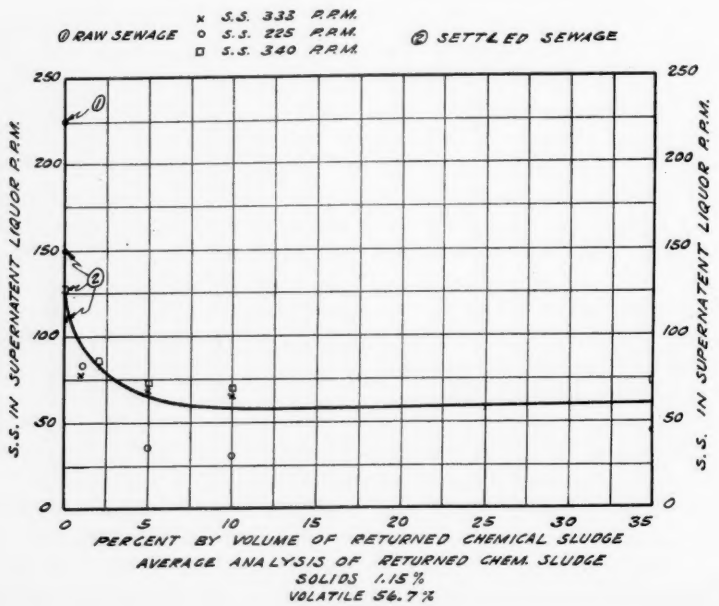


FIG. 6.

cent (see Figure 8). The supernatant liquor from this sludge was sparkling clear * (4) (5).

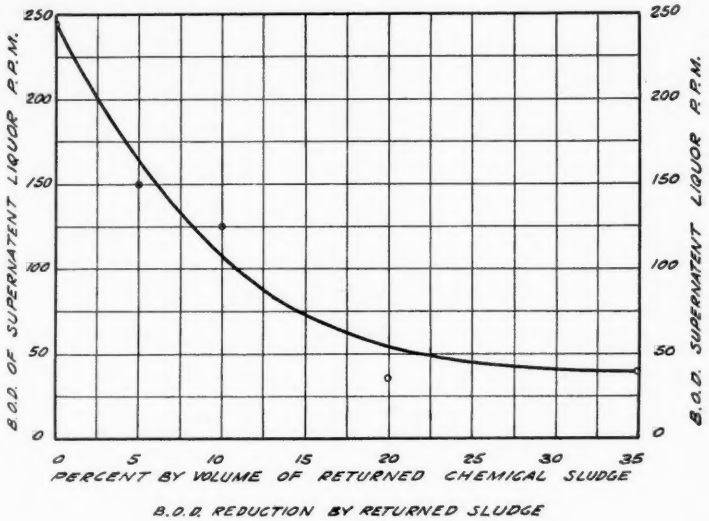


FIG. 7.

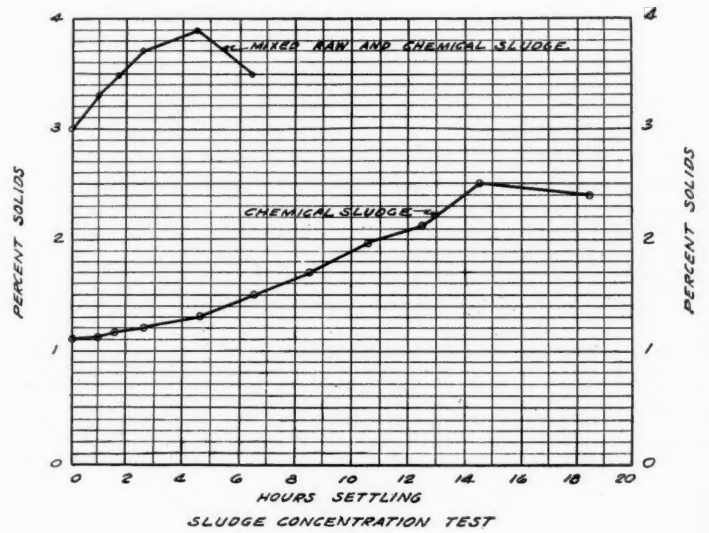


FIG. 8.

* "When a solution of ferric salt is treated with an alkali, there is formed a voluminous, gelatinous precipitate which is commonly called ferric hydroxide and assigned formula $Fe(OH)_3$ The extent to which this terminology is fixed in our chemical literature is evidenced by its almost universal use in our textbooks, although four decades ago van Bemmelen showed not only that there is no definite hydrate of the formula $Fe(OH)_3$ or $Fe_2O_3.3H_2O$, but that no other hydrate is formed by the usual method of precipitating the oxide. The viscous voluminous precipitate when first formed may be represented approximately by the formula

After about fifteen hours at room temperature, the sludge will become septic and start bulking. We are attempting to delay this septic action by chlorination.

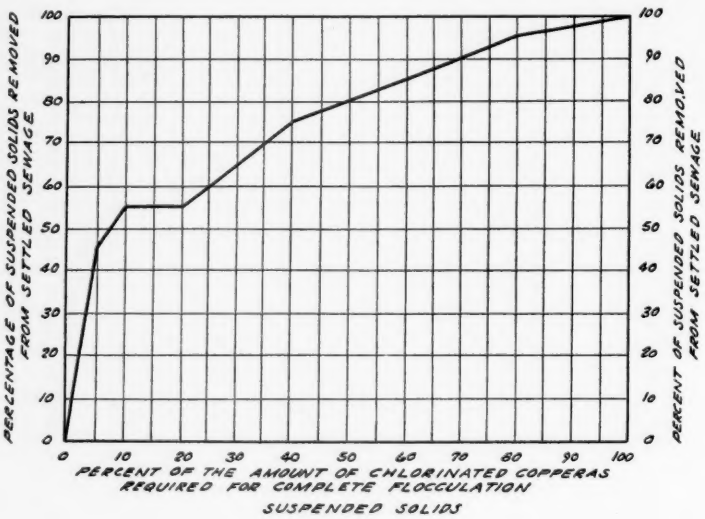

PERCENTAGE OF SUSPENDED SOLIDS REMOVED FROM SETTLED SEWAGE
PERCENT OF SUSPENDED SOLIDS REMOVED FROM SETTLED SEWAGE
0 10 20 30 40 50 60 70 80 90 100
PERCENT OF THE AMOUNT OF CHLORINATED COPPERAS REQUIRED FOR COMPLETE FLOCCULATION SUSPENDED SOLIDS

FIG. 9.

By allowing the mixed chemical and raw sludge to stand approximately five hours, the solids content increased from 3 to 4 per cent. After approximately five hours, and at room temperature, this mixed sludge started to bulk.

We are experimenting with activated carbon on the theory that a few particles of entrapped carbon in each particle of floc will adsorb the hydrogen sulphide and other reducing agents, and prolong the time before the sludge becomes septic, thus making it possible to further increase the concentration.

Partial Treatment.—In order to ascertain the feasibility of varying the degree of treatment obtained by a chemical process, by varying the amount of coagulant added, laboratory study was made of the effect of different doses of chlorinated copperas upon settled sewage. This was done by flocculation tests in which varying amounts of coagulant were added to the settled sewage, which was then flocculated for 30

$Fe_2O_3 . \pm 20H_2O$, but it loses water, gradually attaining a composition that varies with the time, temperature, and the pressure of the water vapor in contact with it. A composition corresponding to a definite hydrate is, therefore, purely accidental, depending as it does on the exact method of formation, the method of drying, the temperature, and the age of the sample. Precipitated oxides like ferric oxide which contain varying amounts of water adsorbed by the oxide particles are called hydrous oxides to distinguish them from hydrates, in which the water is chemically combined in definite stoichimetric proportions. . . . On standing, the primary colloidal particles of hydrous oxides grow and lose water spontaneously, causing the mass to assume a less gelatinous and more granular character. . . .

"Although the rapid precipitation of a hydrous oxide usually gives a gelatinous mass with a supernatant liquid, it is frequently possible to bring about uniform precipitation throughout the entire solution with the formation of a jelly which differs from a gelatinous precipitate in that all the liquid is enclosed by the precipitated phase." . . .

minutes and settled for one hour. The results of this work are shown in Figures 9, 10, and 11. For the purpose of comparing the results of the various tests, the amount of iron for complete clarification was determined and called 100 per cent, and the amount of suspended solids, B.O.D., or turbidity removed by this amount of iron was called 100 per cent. As shown in Figures 9, 10, and 11, the first 5 per cent of iron added removed 45 per cent of the suspended solids from the settled sewage, and the first 50 per cent of iron added removed 80 per cent of the suspended solids; the first 5 per cent of iron added removed 35 per

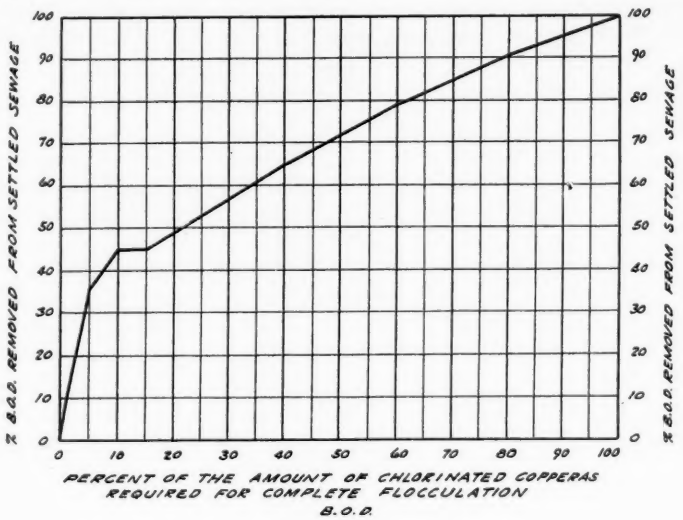

% B.O.D. REMOVED FROM SETTLED SEWAGE
% B.O.D. REMOVED FROM SETTLED SEWAGE
0 10 20 30 40 50 60 70 80 90 100
PERCENT OF THE AMOUNT OF CHLORINATED COPPERAS REQUIRED FOR COMPLETE FLOCCULATION B.O.D.

FIG. 10.

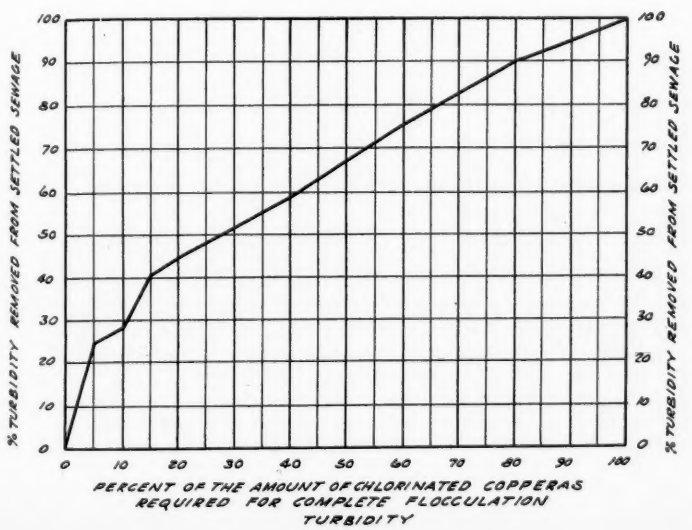
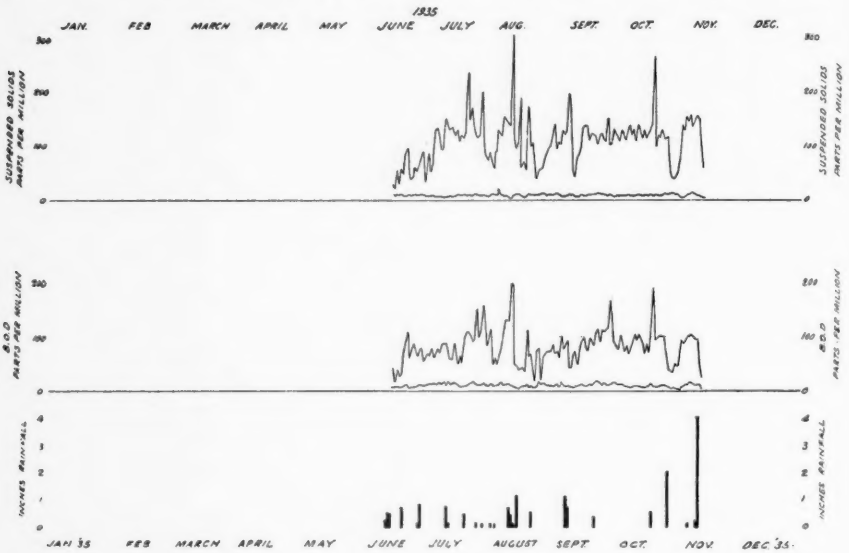

% TURBIDITY REMOVED FROM SETTLED SEWAGE
% TURBIDITY REMOVED FROM SETTLED SEWAGE
0 10 20 30 40 50 60 70 80 90 100
PERCENT OF THE AMOUNT OF CHLORINATED COPPERAS REQUIRED FOR COMPLETE FLOCCULATION TURBIDITY

FIG. 11.

cent of the B.O.D., and the first 50 per cent of iron added removed over 70 per cent of the B.O.D.; the first 5 per cent of the iron added removed 25 per cent of the turbidity, and the first 50 per cent of iron added removed 65 per cent of the turbidity. In other words, the last half of the iron dosage required for complete clarification removes only 20 per cent of the suspended solids, 30 per cent of the B.O.D. and 35 per cent of the turbidity.

Operating Results With Chemicals

Results obtained during the period from June to November, 1935, when chemicals were used, are shown in Fig. 12. The uniform char-



Shades Valley Plant.
Suspended Solids and B.O.D. Removal.

Fig. 12.

acter of the effluent should be noted, as shown by the record of analyses for suspended solids and B.O.D.

Average results of analyses of the chemical sludge are shown in Table VII.

Table VII.—*Chemical Sludge*

	Per Cent		
	Max.	Min.	Av.
Solids	3.10	0.80	1.61
Volatile Matter	62.9	34.4	45.4
Total Iron			13.5
pH	6.8	6.7	6.7

Summary

1. Results obtained at the Shades Valley Plant have exceeded the expectations of the designing engineers and have justified the selection of the process as originally adopted.

2. Continued satisfactory results have been obtained at a very reasonable cost.

3. Digestion of mixed raw and chemically treated sludge has been accomplished by means of two-stage digestion, with the production of an excellent overflow liquor comparable in strength to raw sewage.

4. Coagulation by means of a ferric iron salt, without previous pH value adjustment, is considerably cheaper than with the addition of acids or alkali, in Birmingham sewage.

5. Although the preliminary removal of settleable solids did not result directly in a reduction of chemicals required, pre-settling has definite advantages in a chemical precipitation plant, especially when combined with return of chemical sludge.

6. Returned chemical sludge will materially reduce suspended solids and B.O.D. in the primary settling tank. Continued re-circulation of sludge may give trouble because of reduction of ferric iron.

7. Laboratory experiments indicate that mixed or chemical sludge may be readily concentrated by storage; a higher final density being obtained in the case of the mixed sludge.

8. The coarser non-settleable solids coagulate more easily, making possible a varying degree of treatment, depending on the amount of chemicals added to Birmingham sewage.

Acknowledgments

This work was done by the Jefferson County Sanitary Department of which the writer is Sanitary Engineer. M. E. Boriss is Assistant Engineer in charge of plant operation. Paul B. Krebs is Chemist and Operator at the Shades Valley Plant.

The experimental work was done in the central laboratory at the Ensley Plant where R. C. Barton, Jr., is Chief Chemist.

We were assisted in this experimental work by the Jefferson County Works Division of the Alabama Relief Administration.

References

1. H. H. Hendon, "The Shades Valley Chemical Precipitation Plant at Birmingham, Alabama." *Water Works and Sewerage*, March, 1935.
2. H. H. Hendon, "Chemical Treatment of Sewage at Birmingham, Alabama." *Water Works and Sewerage*, December, 1933.
3. Elson T. Killam, "Hourly Load Variations as a Factor in Sewage Treatment and Plant Operation," *Water Works and Sewerage*, July, 1934.
4. Harry Boyer Weiser, "The Hydrous Oxides." McGraw-Hill Book Co.
5. Arthur W. Thomas, "Colloid Chemistry." McGraw-Hill Book Co., 1934.
6. Linn H. Enslow, "Sewage Treatment by Modern Chemical Methods." *Civil Engineering*, April, 1935.

THE ECONOMICS OF VARIOUS METHODS OF SLUDGE DISPOSAL *

By A. J. Fischer

Sanitary Development Engineer, The Dorr Company, Inc.

Introduction

During the last few years a number of advances have been made in the treatment and disposal of sewage sludge by improved methods of digestion, dewatering on vacuum filters and final disposal by incineration.

Elimination of the digestion step by direct filtration and incineration of raw sludge has been advanced as an alternate method of complete disposal, while centrifuges and some types of sludge dryers are still in an experimental stage. Whether or not these more recent innovations will be made to compete successfully with the older methods of sludge treatment can be determined only after a number of plants now under design or being contemplated reach the operating stage, so that reliable cost data may be collected and possible improvements made.

Based on information obtained from semi-plant and regular plant scale tests there appears to be no question that all types of sludges now obtainable in sewage treatment may be dewatered and incinerated in either a raw or a digested state. There is a question, however, whether certain procedures are economically justified. While economics are not always a deciding factor because of certain local conditions, they are an important one and warrant careful consideration.

The purpose of this paper is to present an economic analysis of filtration and incineration of raw primary and mixed sludges as against digestion of these sludges followed by either open or covered sand-bed drying, or by vacuum filtration, with or without incineration. The conclusions presented are based on present available plant and large-scale experimental data.

Scope of Analysis

In order to make a comprehensive survey of the field, installation and operating costs have been computed for 2, 5, 10, 25, 50 and 100 m.g.d. plants producing the following types of sludges: primary; primary plus trickling filter; primary plus chemically precipitated; and primary plus activated sludge. In addition, costs were figured for a combination of digested primary plus undigested activated sludge.

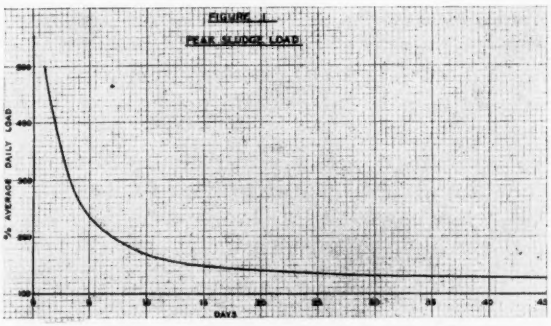
In the three smaller plants, with ratings of 2, 5 and 10 m.g.d., it is assumed that the filters and incinerators are operated an average of 8 hours per day. Continuous operation is assumed for the three larger plants.

* Presented at the Eighth Annual Meeting of the New York State Sewage Works Association, New York City, January 15, 1936.

Peak Sludge Loads

An important consideration in the design and operation of sludge handling plants is that regarding peak sludge loads. Very little thought had been given to this point in the past where digestion was employed because the digesters, which were always liberally designed, acted as "balancing tanks" and smoothed out these peaks. Now, with tendencies toward short-time digestion or elimination of digestion, this factor has a greater bearing on plant design. It is believed that this fact was first appreciated by the Chicago Sanitary District in connection with their recent work on raw primary and activated sludge incineration.

Figure 1 shows a typical relationship between peak raw sewage



solids loads and duration of time when these peaks persist. The data are from a composite study of peak loads obtained at Chicago, Cleveland, Columbus, Syracuse, Rochester and other large American cities. The curve was prepared by Mr. R. A. Allton,[1] Sanitary Engineer of Columbus, Ohio, in connection with the study of the design of a sludge handling plant for the new Columbus treatment plant. This curve is characteristic of large cities having a number of sewers laid on flat grades. In such cases the abnormal sludge loads obtained during short periods are occasioned by flushing out of the sewers during storm flows. These peaks are more marked where the sewage is from combined systems and where the sewer system covers a large area. In smaller plants, say of less than 10 m.g.d. capacity, these peaks may be of lesser intensity and possibly of a shorter duration.

While the curve of Figure 1 is not intended as a yardstick in the design of all plants, nevertheless, where specific local data are lacking it shows what might be expected. Therefore, the probability of obtaining these peaks must be recognized by furnishing sludge handling facilities to take care of these peaks or by supplying sufficient sludge storage capacity to reduce them to a figure consistent with the lesser sludge handling facilities that may be provided.

Experience indicates that if raw primary sludge is stored longer than about two days in summer it becomes septic, giving rise to odor nuisances and requiring a greater amount of coagulant preparatory to

dewatering on vacuum filters. Therefore, assuming that peak loads similar to those shown in Figure 1 are obtained, filter and incinerator capacities should be furnished to handle 375 per cent of the daily average sludge load where raw sludge is filtered and incinerated. Similarly, where short-time digestion periods of 20 days are contemplated, the filters and incinerators should be designed for 140 per cent peaks. Where 20-day primary plus 30-day secondary digestion is used, these units should be capable of handling 125 per cent peaks. In the case of activated sludge, 125 per cent peak load designs are adequate as the aeration tanks may be used to store this type of sludge.

Basis of Design

In this comparison, it is assumed that when raw sludge solids are to be incinerated, the wet sludge may be stored for two days in mechanically equipped sludge thickeners prior to dewatering and incineration. In order to show the effect of widely divergent conditions, maximum peak loads of 125 per cent and 375 per cent of the daily average have been assumed.

Where digestion is used, it is assumed that a 20-day primary and a 30-day secondary digestion period is provided ahead of vacuum filtration, while a 20-day primary and a 60-day secondary digestion period is provided in the case of sand-bed drying. In all cases of digestion, 125 per cent peak loads are assumed for the dewatering and incinerating units.

Detailed design data are given in Table I. In each case, where secondary treatment is used, it is considered that it is preceded by primary sedimentation, whereby 60 per cent of the suspended solids are removed. Chemical treatment is taken as treatment of pre-settled sewage by means of 30 p.p.m. of ferric chloride.

Suspended solids in the raw sewage are taken as 0.17 lb. per capita or 204 p.p.m. with a flow of 100 gal. per capita per day, of which 70 per cent is volatile matter. This is a fair average for a domestic sewage from a separate system where no predominating trade wastes are present. Total suspended solids removals are as shown. In the case of trickling filter treatment it is assumed that 8 per cent of the raw sludge solids, or 135 lb. per mil. gal. of sewage, are digested in the trickling filter and do not have to be handled in the digestion or dewatering operation.

In computing the size of sludge thickeners or storage tanks, three feet are added to the sludge depth for supernatant liquor to assure an adequate clarification zone at all times. These units are operated on a continuous basis, the sludge depth being varied to give the required detention period. In warm climates where septic action may occur in less than two days, small doses of chlorine may be applied to delay this septic action. These tanks have a floor slope of one inch per foot.

Digestion tank sizes are calculated on the basis of the amount of total dry solids, volatile matter, sludge moisture, volatile matter reduction in each digestion stage, and the reduction in sludge moistures

TABLE I.—*Design Data*

Sewage flow = 100 gals./capita. Raw sewage solids taken at 0.17 lb./capita, 70% volatile matter

	Primary Treatment	Trickling Filter Treatment	Chemical Treatment	Activated Sludge Treatment	Activated Sludge Alone
Overall suspended solids rem.	60%	85%	80%	95%	
Raw sludge, dry solids/m.g.d.	1020 lb.	1310 lb.	1525 lb. (Incl. chem.)	1615 lb.	
Raw sludge, % moisture	94	95	95	96	98.8
Raw sludge, thickener final % moisture	90	92	92	93	96
Raw sludge, thickener aver. % moisture	92	93.5	93.5	94.7	97.4
Thickener sludge detention	2 days	2 days	2 days	2 days	2 days
Digested sludge, dry solids/m.g.d.	555 lb.	710 lb.	905 lb.	1035 lb.	
Digested sludge, % moisture	91.2	93.1	93.1	94.5	
Digester, % solids reduction	45.5	45.5	41	36	
Digester, % volatile reduction	65	65	58.5	51.5	
Digester, gas, cu. ft. per m. gals.	7900	10,200	10,650	9850	
Digestion period:					
Primary	20 days	20 days	20 days	20 days	
Secondary:					
Filtration	30 days	30 days	30 days	30 days	
Sand beds	60 days	60 days	60 days	60 days	
Total digester capacity:					
Cu. ft./capita (30-day secondary)	0.98	1.53	2.02	2.28	
(60-day secondary)	1.23	1.87	2.15	2.78	
Cu. ft./lb. volatile matter added day					
(30-day secondary)	13.7	16.7	21.2	20.1	
(60-day secondary)	17.2	20.4	22.6	24.6	
Drying bed loadings, lb.					
Dry solids/sq. ft./year:					
Open beds	35	30	30	25	
Covered beds	70	60	60	50	
Incinerator, average tons water evaporated/24 hrs./m. gals. sewage:					
Raw sludge	1.30	2.08	2.48	2.97	
Digested sludge	0.70	1.02	1.18	1.93	

in the secondary tank. Where continuous agitation is provided in the primary tank the required volume is equal to the desired digestion period in days, multiplied by the volume of wet sludge added per day. The volume of the secondary tank depends on the type of sludge being treated. For a 30-day storage period the sludge capacity in cu. ft. is equal to the pounds of dry settled solids per day multiplied by the factor 3.25 in the case of primary sludge. For trickling filter and chemical sludge, the factor used is 4.05 and for activated sludge 4.80. To the secondary tank sludge depths are added three feet for supernatant liquor clarification. The secondary tanks have floor slopes of three inches per foot.

Gas holders are provided on the secondary tanks to give a gas storage of 40 per cent of the daily average production. This allows for utilization of 90 per cent of all the gas produced.

Vacuum filters are designed on the basis of capacities as given in Table II. This table shows that filter rates, conditioner requirements,

TABLE II.—*Sludge Filtration*

Type of Sludge	Conditioner % of Dry Sludge Solids		Filter Capacity Lb./Sq. Ft./Hr.	Cake Moisture %
	CaO	$FeCl_3$		
Raw Sludges:				
Primary	10	3	5	68
Primary plus trickling filter	12	3	4	72
Primary plus chemical ($FeCl_3$)	12	3	4	72
Primary plus activated	0	6	4	78
Chemical ($FeCl_3$)	10	5	2	80
Chemical (CaO + $FeCl_3$)	8	3	6	66
Activated	0	6	2.5	80
Digested Sludges:				
Primary	10	2	6	68
	or 0	6	6	72
Primary + trickling filter	12	2	6	70
	or 0	7	6	74
Primary + chemical ($FeCl_3$)	12	2	6	68
	or 0	7	6	72
Primary + activated	0	8	2.5	78
Chemical ($FeCl_3$)	12	2	4	70
	or 0	7	4	74
Chemical (CaO + $FeCl_3$)	10	2	6	68
	or 0	6	6	72
Activated	0	10	2.5	80
Mixed Sludges:				
Digested primary + undigested and activated	0	6	4.5	75

and cake moistures vary widely depending on the nature of the sludge. It further shows that the mere reference to a sludge as being "raw" or "digested" is misleading unless the specific source of the sludge is also designated. It is interesting to note that on all raw sludges other than activated, combinations of lime and ferric chloride are used for conditioning, while on all digested sludges other than activated, ferric chloride alone or combinations of lime and ferric chloride may be used. In all cases where activated sludge is included, ferric chloride alone is used, lime having little or no value when used in combination with the ferric salt. Chlorinated copperas and ferric sulphate may be used as a substitute for ferric chloride. It is the writer's experience that about 25 per cent more chlorinated copperas or 75 per cent more ferric sulphate must be used than ferric chloride, on an iron content basis.

Incinerators are designed on the basis of water evaporation using the sludge moistures given in Table II. It may be noted that the weight of dry solids in the filter cake is increased over that obtained from the thickeners or digesters because of the conditioner added. This may

be a considerable item and should be taken into consideration. Assuming that the lime is entirely converted to calcium carbonate, and the ferric chloride to ferric hydroxide, the increase in dry weight in the filter cake is 1.78 per cent for each per cent lime, and 0.66 per cent for each per cent ferric chloride added.

Sand-drying bed areas are based on the pounds of dry solids that can be dried per sq. ft. in one year. These figures are based on actual operating results and within limits are independent of the moisture of the sludge applied. The moisture of the air-dried sludge is taken at 60 per cent for primary, trickling filter, and chemical treatment sludge and 65 per cent for activated sludge.

Installation Costs

Installed costs of sludge thickeners, digesters, vacuum filters and incinerators are given in Figures 2 to 5, inclusive. Open sand bed costs are taken at 50 cents and covered beds at $1.80 per square foot. To costs of all structures are added 5 per cent for engineering and 15

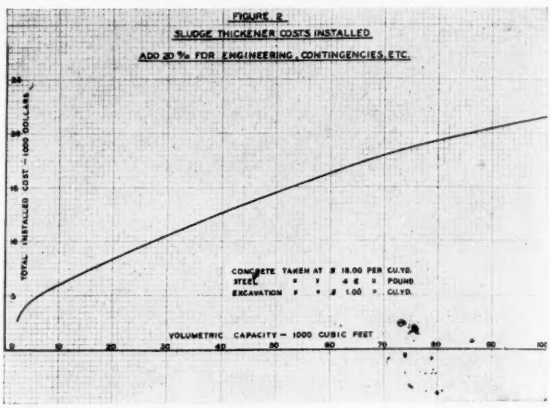


FIGURE 2
SLUDGE THICKENER COSTS INSTALLED
ADD 20 % FOR ENGINEERING, CONTINGENCIES, ETC.
TOTAL INSTALLED COST - 1000 DOLLARS
CONCRETE TAKEN AT $ 18.00 PER CU.YD.
STEEL " " .6 " " POUND
EXCAVATION " " 1.00 " CU.YD.
VOLUMETRIC CAPACITY - 1000 CUBIC FEET

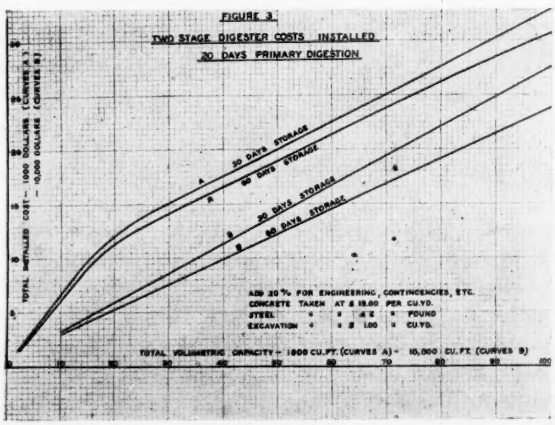


FIGURE 3
TWO STAGE DIGESTER COSTS INSTALLED
20 DAYS PRIMARY DIGESTION
TOTAL INSTALLED COST - 1000 DOLLARS (CURVES A) - 10,000 DOLLARS (CURVES B)
30 DAYS STORAGE
60 DAYS STORAGE
30 DAYS STORAGE
60 DAYS STORAGE
ADD 20 % FOR ENGINEERING, CONTINGENCIES, ETC.
CONCRETE TAKEN AT $ 18.00 PER CU.YD.
STEEL " " .6 " " POUND
EXCAVATION " " 1.00 " CU.YD.
TOTAL VOLUMETRIC CAPACITY - 1000 CU.FT. (CURVES A) - 10,000 CU.FT. (CURVES B)

per cent for contingencies, such as inlet and outlet conduits and piping for thickeners; piping and control chambers for digesters; chemical storage, piping, etc., for vacuum filters; sludge handling equipment for

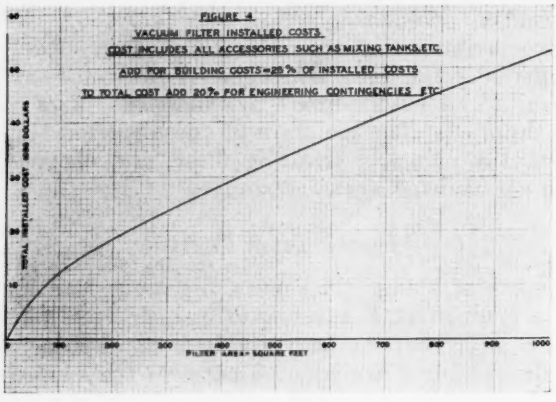


FIGURE 4
VACUUM FILTER INSTALLED COSTS
COST INCLUDES ALL ACCESSORIES SUCH AS MIXING TANKS, ETC.
ADD FOR BUILDING COSTS = 25% OF INSTALLED COSTS
TO TOTAL COST ADD 20% FOR ENGINEERING CONTINGENCIES ETC.
TOTAL INSTALLED COST IN 1000 DOLLARS
FILTER AREA - SQUARE FEET

sand drying beds; and ventilating equipment, etc., for incinerators. In no case is the cost of land included.

In all cases, the costs of the various structures includes concrete at $18.00 per cubic yard, reinforcing steel at 4 cents per pound, and excavation at $1.00 per cubic yard, as well as the costs of all equipment, freight and haulage, erection, wiring, foundations, etc.

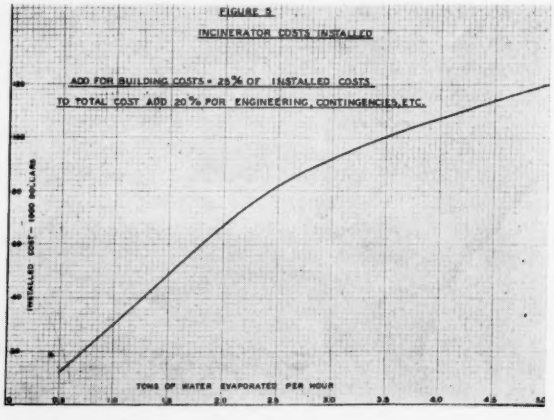
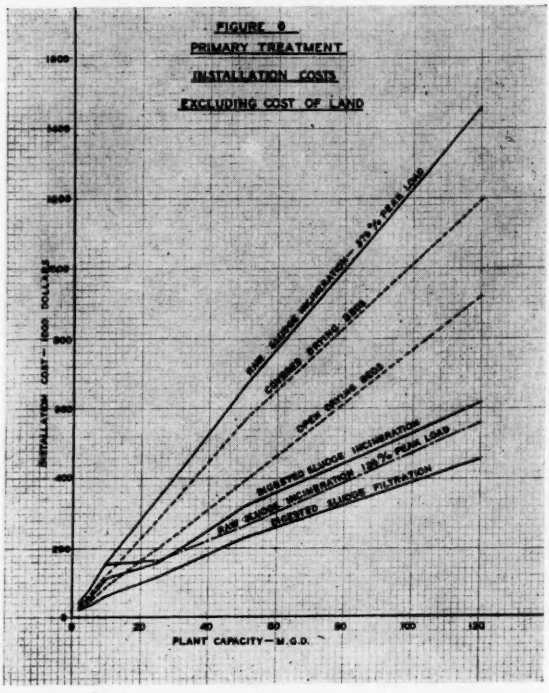


FIGURE 5
INCINERATOR COSTS INSTALLED
ADD FOR BUILDING COSTS = 25% OF INSTALLED COSTS
TO TOTAL COST ADD 20% FOR ENGINEERING, CONTINGENCIES, ETC.
INSTALLED COST - 1000 DOLLARS
TONS OF WATER EVAPORATED PER HOUR

There appears to be some discrepancy in the lower range of the incinerator cost curve in that the cost increases a little more rapidly than the rated capacity figure below a water evaporation of 2.0 tons per hour. The writer has been informed that this apparent inconsistency may be explained by the fact that the smaller units are less expensive per ton of water evaporated, due to a sacrifice in efficiency which reduces the equipment cost.

Total Installation Cost Comparisons

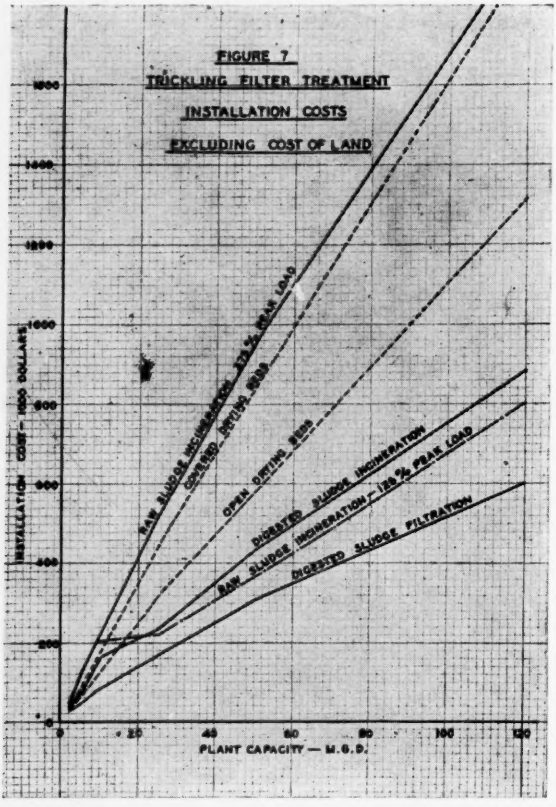
Total installation costs of the various types of plants are shown in Figures 6 to 9, inclusive. Primary treatment costs as plotted in Figure 6 show that for plants of less than 10 m.g.d. capacity the installa-



tion costs of raw sludge incineration plants are highest, whether or not provision is made for the high peak loads. Raw sludge incineration is followed by digested sludge incineration, covered and open drying beds and digested sludge filtration, in the order named. In the larger plants, raw sludge incineration with 375 per cent peak loads is still the most expensive system. This is followed by covered and open beds, digested sludge incineration, raw sludge incineration with 125 per cent peak loads and finally digested sludge filtration, which persists at the lowest level throughout the entire range of plant sizes.

The same trends are noted for trickling filter and chemical treatment installation costs, as shown in Figures 7 and 8, respectively. In the case of Figure 9, showing activated sludge treatment costs, however, a difference is noted in that while for plants below 5 m.g.d. capacity the same relationships hold as before, there is a change in order, starting at the 10 m.g.d. plant. Here, digestion with covered drying beds is the most expensive plant. This is followed by digested sludge incineration, raw sludge incineration, open beds, and digested sludge filtration. Above 25 m.g.d. raw sludge incineration with 125 per cent

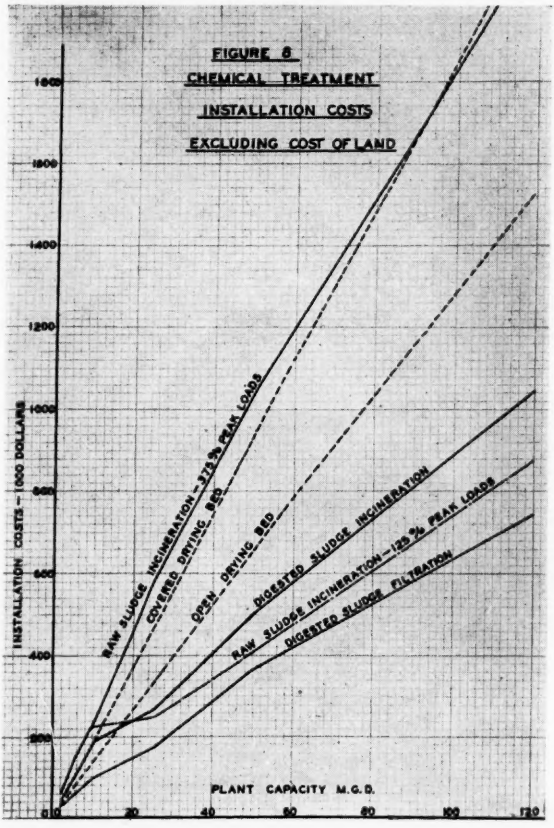
peak loads is less expensive than digested sludge filtration, while covered drying beds are the most expensive.



It has long been known that digested activated sludge is relatively difficult to dewater on vacuum filters. In view of this difficulty the natural solution in the larger plants would appear to comprise a system wherein only the primary sludge is digested and the resulting digested sludge is mixed with undigested activated sludge that has been subjected to a thickening operation. The resulting combination may then be dewatered. Curves showing the costs of such an arrangement with and without incineration are given in Figure 9. These show that the lowest cost plant is obtained where the combination is filtered. Incineration, if included, brings the overall cost lower than when all the sludge is digested and incinerated, but higher than where raw sludge incineration is assumed with 125 per cent peak loads.

In all of the foregoing total plant cost comparisons, it is noted that there is a sharp break at 10 m.g.d. in the curves of raw and digested sludge incineration where 125 per cent peak loads are assumed. This

is due to the fact that below 10 m.g.d., 8 hours daily operation of filters and incinerators is assumed while above 25 m.g.d. the operation is continuous, *i.e.*, 24 hours per day, sufficient time being taken out for filter cloth cleanings, etc. This reduces the proportionate cost of equipment for the larger plants.



Where 8-hour operation of filters and incinerators is assumed, equipment is designed to handle only 125 per cent of the daily average sludge load even where 375 per cent raw sludge peak loads may be obtained. In such cases, the peaks may be satisfactorily handled by resorting to continuous 24-hour operation until the peaks subside. Where 24-hour operation is assumed, however, the filter and incinerator plants are trebled to take care of the high peak on raw sludge.

Operating Costs

The schedule of operating charges used in this analysis is shown in Table III. These estimates require no further comment other than to

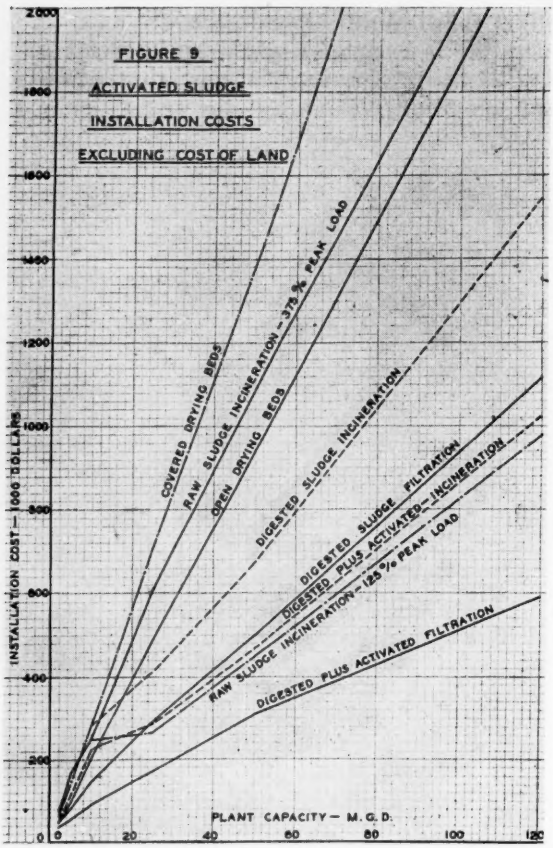


FIGURE 9
ACTIVATED SLUDGE
INSTALLATION COSTS
EXCLUDING COST OF LAND
INSTALLATION COST — 1000 DOLLARS
PLANT CAPACITY — M. G. D.
COVERED DRYING BEDS
RAW SLUDGE INCINERATION — 375% PEAK LOAD
OPEN DRYING BEDS
DIGESTED SLUDGE INCINERATION
DIGESTED SLUDGE FILTRATION
DIGESTED PLUS ACTIVATED — INCINERATION
RAW SLUDGE INCINERATION — 125% PEAK LOAD
DIGESTED PLUS ACTIVATED FILTRATION

TABLE III.—*Annual Operating Charges*

Item	Charge
1. Fixed charges	7½% of total installation cost
2. Labor	60¢ per man-hour
3. Power	1¢ per kilowatt-hour, or 0.20¢ per kilowatt-hour where digester gas is used for power
4. Chemicals	See Table IV
5. Fuel	4¢ per gal. of oil
6. Supplies	1½% of erected cost of equipment
7. Maintenance and repairs	2% of erected cost of equipment
8. Sand replacement	$1.15 per ton
9. Sludge removal from beds	50¢ per ton of sludge cake
10. Sludge or ash haulage	50¢ per ton

point out that sludge removal and haulage charges may be representative for very large plants where there is no local demand for the sludge as a fertilizer and where there are no available dumps near the plant site. In some instances, especially in small and medium-sized plants, the sludge cake is sold or given away after removal from drying beds, while in others the purchaser removes the sludge when requested. In

still other cases, the sludge is processed and sold at a higher price after removal from the filters or drying beds. In a general analysis of this kind, it is obviously impossible to take all of these variable factors into consideration. In analyzing any specific example, however, outlets for sale of sludge should be considered, as final sludge disposal may be a costly item.

Where an excess of gas is available over that required for incineration, it is considered as being available for power by the use of gas engines. According to Walraven,[2] operating costs at Springfield, Ill., including 12 per cent of equipment costs for fixed charges, amount to 0.13 cents per kw. hr. of power generated. Adding fixed charges for a generator and other electrical control devices brings this cost of power generation to 0.20 cents per kw. hr. of power input.

Table IV shows costs of lime and ferric chloride. Here again local

TABLE IV.—*Sludge Conditioner Costs. Middle Atlantic and Midwestern States*

1. *Delivered Cost of Lime* (*CaO*)
Freight, etc., taken at $4.00 per ton in carload lots (18 tons).
Freight, etc., taken at $8.00 per ton in less carload lots.
Maximum storage taken at 4 months.

Amount Used per Year	Cost per Ton Delivered
Less than 120 tons (less carloads)	$20
120–1000 tons (carloads)	12
Over 1000 tons	10

2. *Delivered Cost of Ferric Chloride* (Anhydrous basis)

Type of Salt	Amount Used per Year	Cost per Pound $FeCl_3$ Delivered
Anhydrous	Less carloads (1 T. min.)	4 cents
Anhydrous	Carloads (18 T. minimum)	3.3
Liquid (40–45% $FeCl_3$)	40–100 tons (carload)	2.5
Liquid	100–1000	2.15
Liquid	Over 1000	2.0

Maximum storage of liquid ferric chloride taken at 6 months.
When the liquid is purchased it is assumed that there is a railroad siding at the plant site.

conditions are an important consideration, especially in regard to the price of ferric chloride or other iron salts. Examples of variations in the price of ferric chloride are given in the following schedule showing some 1935 prices.

Anhydrous Ferric Chloride

Less Carload Prices (1 Ton Minimum)		Carload Prices (18 Tons Minimum)	
Ohio	3.5¢ per lb.	Maryland	3.15¢ per lb.
Wisconsin	4.13¢ per lb.	North Carolina	3.33¢ per lb.
Eastern New York	4.25¢ per lb.	So. Dakota	3.40¢ per lb.

Liquid Ferric Chloride (Tank Cars)

Location	Approx. Tons Per Year	Cost per Pound Anhyd. $FeCl_3$
Dearborn, Mich	500–1000	1.50
Milwaukee, Wisc.	2000	1.92
Chicago, Ill.	500	1.99
Central Illinois Plant	40	2.40

All prices quoted are delivered prices. In the case of Dearborn there is no freight added because of nearby production and truck delivery. From this, it can be seen that the price of ferric chloride depends on geographical location, amount of ferric chloride required per year, and whether or not there is a railroad siding at the plant to permit ready unloading of the liquid.

For the purpose of this analysis it is assumed that there is a railroad siding at all except the 2 and 5 m.g.d. plants. It is also assumed that where the yearly tonnage is between 18 and 40 tons the 3.3 cents per pound rate will apply.

Table V gives a schedule of labor, power and fuel requirements.

TABLE V.—*Operating Charges—Labor, Power and Fuel*

Item	Quantity Man-Hours per Day					
	2 m.g.d.	5 m.g.d.	10 m.g.d.	25 m.g.d.	50 m.g.d.	100 m.g.d.
Labor:						
Thickeners	4	4	4	12	12	24
Digesters	8	8	8	24	24	36
Miscellaneous	4	8	8	16	16	32
Vacuum filters	1 man-hour per hour operation of one unit. ¼ man-hour per hour operation of each additional unit.					
Incinerators	1 man-hour per hour operation of one unit. ½ man-hour per hour operation of each additional unit.					
	K.W. Hrs. Continuous					
	20′ dia.	40′	60′	80′	100′	
Power:						
Thickeners	0.23	0.46	0.68	0.80	1.02	
Digesters	—	1.1	2.2	4.4	6.6	
Sludge pumps	2.24 kw. at 50 g.p.m. 30′ total head.					
Vacuum filters	6.5 kw. per 100 sq. ft. filter area.					
Incinerators	6.875 kw. per ton of water evaporated.					
Power credit for digester gas	1 B.H.P. hr. per 18 cu. ft. gas.					
Fuel	5.94×10^6 B.T.U.'s per ton of water evaporated. Add for start-ups, etc., 2.5 gals. oil/m.g. in 2, 5, 10 m.g.d. plants. Add for start-ups, etc., 0.2 gals. oil/m.g. in 25, 50, 100 m.g.d. plants.					
Heat Credit for Sludges	10,000 B.T.U.'s per pound of combustible matter.					
Heat Credit for Digester Gas	650 B.T.U.'s per cu. ft. gas.					

The power and fuel requirements for incineration are based on Dearborn published results.[3] Additional fuel has been added as shown for start-ups, etc.

Table VI gives a schedule of sand replacement, sludge and ash quantities. Sand quantities have been figured on the basis of the loss of

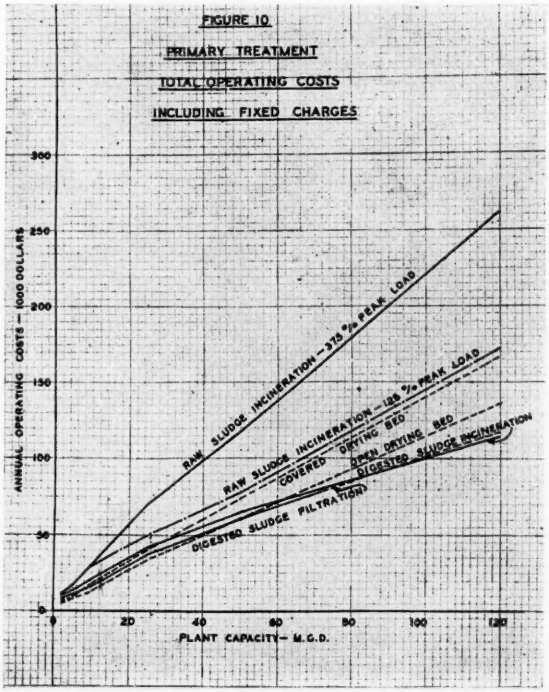
TABLE VI.—*Operating Charges—Sludge or Ash Disposal*

Sand Replacement	Trickling			Activated Sludge	Digested Raw Plus Undigested Activated
	Primary	Filter	Chemical		
Tons sand/yr./m.g.d.	7	9	11.5	14.8	—
Sludge Quantities:					
Cu. yds./yr./m.g.d. (55 lbs. per cu. ft.)					
Sand beds	340	436	554	724	—
Vacuum filters	510	720	860	1136	1076
Ash Quantities:					
Cu. yds./yr./m.g.d. (45 lbs. per cu. ft.)					
Raw sludge	130	166	216	162	—
Digested sludge	110	144	196	162	—

Note: Dry solids in filter cake equals digested sludge solids, plus 1.78 per cent for each per cent CaO added, plus 0.65 per cent for each per cent $FeCl_3$ added as conditioner.

Ash solids equals sludge ash plus 1.0 per cent for each per cent CaO added, plus 0.50 per cent for each per cent $FeCl_3$ added as conditioner.

1/16th inch of sand during each sludge removal. The wet sludge from the digesters is considered as being applied to a depth of about 12 inches.



Total Operating Cost Comparisons

Comparisons of operating costs for the various plant arrangements are shown in Figures 10 to 13, inclusive. The primary treatment costs, as plotted in Figure 10, show that raw sludge incineration, whether or not high peak loads are assumed, results in the highest operating costs, for the entire range of plant sizes. In the 2 and 5 m.g.d. plants, open and covered sand-bed drying bed costs are lowest, while in the larger plants digested sludge filtration, or filtration with incineration, appear to be the preferred arrangement from the standpoint of operating costs. In no case has the interest or cost of land been included in these figures. These items do not amount to an appreciable figure except where sand-bed drying of sludge is used in the larger plants.

The same trend in operating costs is noted for trickling filter and for chemical treatment, as shown in Figures 11 and 12, respectively.

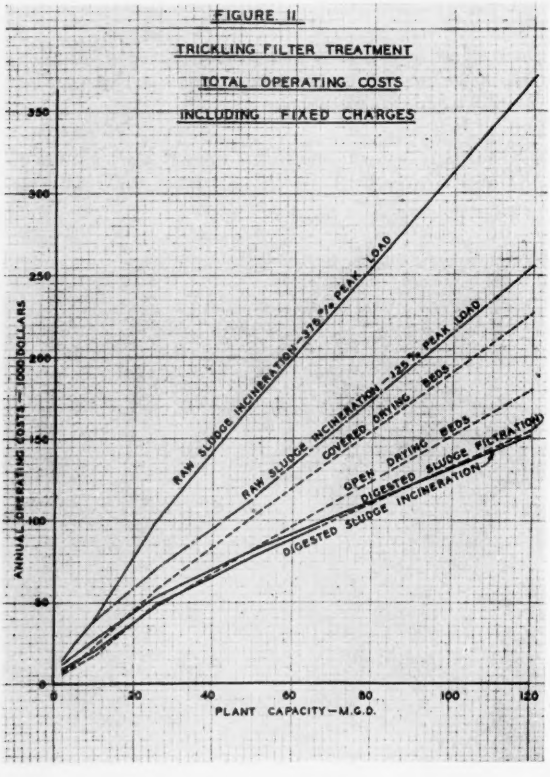
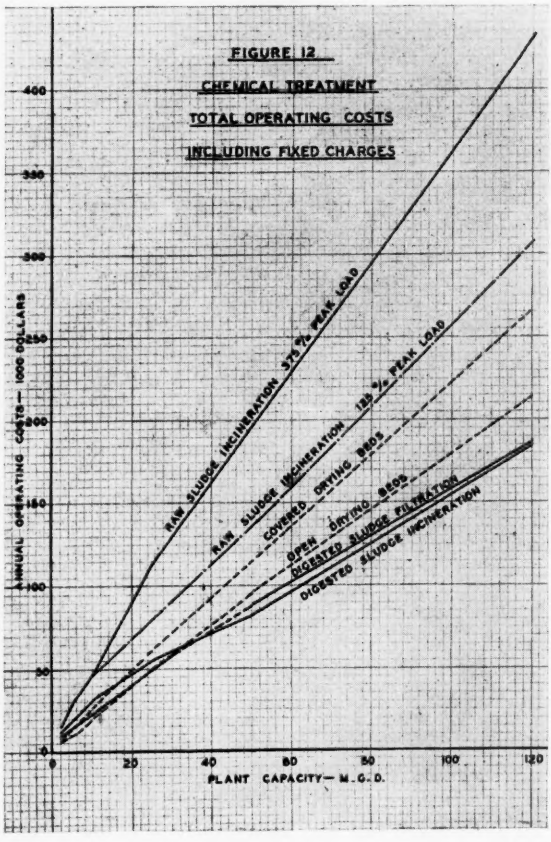


FIGURE 11
TRICKLING FILTER TREATMENT
TOTAL OPERATING COSTS
INCLUDING FIXED CHARGES
ANNUAL OPERATING COSTS — 1000 DOLLARS
PLANT CAPACITY — M.G.D.
RAW SLUDGE INCINERATION — 175 % PEAK LOAD
RAW SLUDGE INCINERATION — 125 % PEAK LOAD
COVERED DRYING BEDS
OPEN DRYING BEDS
DIGESTED SLUDGE FILTRATION
DIGESTED SLUDGE INCINERATION

The costs for activated sludge treatment given in Figure 13 also follow the same general trend as in the other cases. In addition, however, they show that filtration or filtration and incineration of a mixture of digested primary and thickened undigested activated sludge result in a much lower operating cost than the other mechanical methods, especially for plants of large capacity.

Whether or not the mixed sludge filter cake may be disposed of on dumps without odor nuisance is still a debatable question. Small scale tests indicate that this might be accomplished without difficulty. Until demonstrated on a large scale, however, this particular system is not recommended. Therefore, the lowest cost, where open sand beds are not desired, is to use filtration of the digested mixed sludges for plants



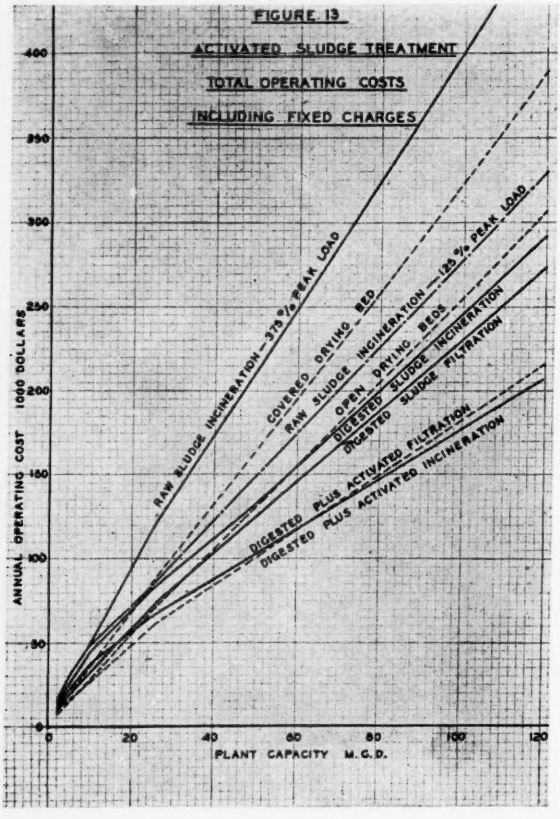
below 15 m.g.d. capacity and incineration of the digested primary and undigested activated sludge mixtures for larger plants.

Figures 14 and 15 show detailed operating costs of the various operations used in raw and digested sludge incineration plants, for handling primary sludge only. The miscellaneous item covers the cost of ash disposal, sludge pumping, and miscellaneous labor.

These figures show conclusively that the costs of sludge filtration and incineration are greatly reduced by digestion, the reduction being far greater than the additional operating costs of the digesters. Savings in power costs by the use of digester gas for power are not deducted in the case of digested sludge.

Additional Cost Reductions

Additional savings in installation and operating costs may be effected, in the case of digested sludge handling, by resorting to short time or partial digestion. It has been demonstrated on a plant scale that a 20-day digestion period will suffice for the stabilization of pri-



mary and mixed sludges. It has further been shown that the filtering qualities of the sludge might be improved by resorting to these shorter periods rather than going to extremely long periods now in general use. In this regard, thermophilic digestion for 2 or 3 days followed by a secondary mesophilic period of 5 to 10 days has distinct possibilities, especially where activated sludge is being handled.

Elutriation of sludge in accordance with the process developed by Genter at Baltimore also appears to have possibilities, especially on digested sludge, as shown by a long series of semi-plant scale tests. Published data by Keefer [4] shows that a 6 lb./sq. ft./hr. filter rate may be obtained using elutriation with only 1 per cent $FeCl_3$ as conditioner. Figure 16 shows the increase in plant installation costs and the net

decrease in operating costs for plants using the process. The installation cost includes present royalty charges, and the installed costs of additional equipment for a 2-stage counter-current washing system. From the savings in chemical costs are deducted fixed charges and costs of power, supplies, maintenance and repairs for the additional equipment required.

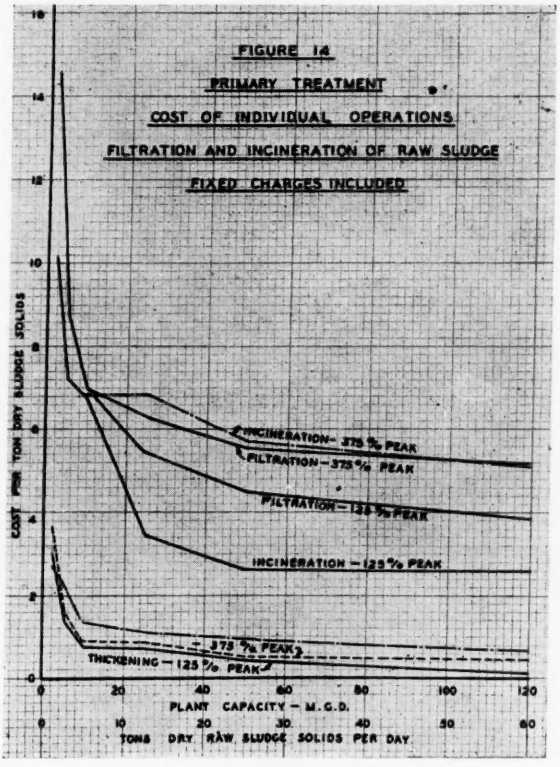
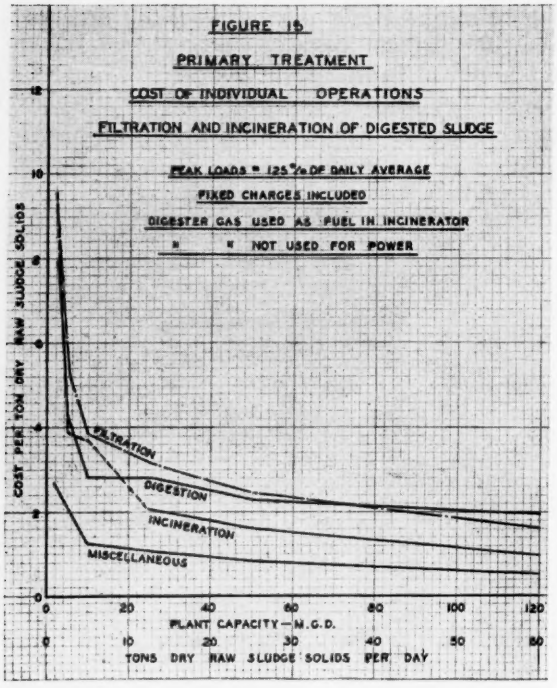


FIGURE 14
PRIMARY TREATMENT
COST OF INDIVIDUAL OPERATIONS
FILTRATION AND INCINERATION OF RAW SLUDGE
FIXED CHARGES INCLUDED
COST PER TON DRY SLUDGE SOLIDS
INCINERATION - 375 % PEAK
FILTRATION - 375 % PEAK
FILTRATION - 125 % PEAK
INCINERATION - 125 % PEAK
375 % PEAK
THICKENING - 125 % PEAK
PLANT CAPACITY - M.G.D.
TONS DRY RAW SLUDGE SOLIDS PER DAY

Genter [5] states that in later laboratory tests, he has obtained a further reduction of ferric chloride to ½ per cent by improved sludge washing. He also claims that the same filter rates can be obtained using 1 per cent alum.

Present Status

The first experimental work on vacuum filtration of raw, digested and mixed sludges was carried out by the writer at Salem, Ohio, on a semi-plant scale in 1929. Since then experimental semi-plant or large scale results have been obtained at Los Angeles, North Toronto, Columbus, Baltimore, Chicago, Palo Alto and Cleveland on a variety of sludges. At the present time, however, the only regularly operating plants besides those operating on activated sludge, are as follows:



Plant	Type of Sludge
Springfield, Ohio	Digested primary
Columbus, Ohio	Digested primary (Imhoff tank)
Cedar Rapids, Ia.	Digested (primary, plus trickling filter plus chemically precipitated packing house waste)
Dearborn, Michigan	Semi-digested primary, plus chemically precipitated
Perth Amboy, N. J.	Raw primary or chemically precipitated
Hagerstown, Md.	Raw primary or raw primary plus activated
Great Neck, L. I.	Raw primary or chemically precipitated
Oklahoma City, Okla.	Raw primary plus chemically precipitated
Rockford, Mich.	Raw primary plus tannery waste
Rockville Center, L. I.	Raw primary plus activated
Winston-Salem, N. Carolina	Chemically precipitated

Plants under construction or definitely under contract, are:

Plant	Type of Sludge
Washington, D. C.	Elutriated digested primary
Coney Island, N. Y.	Digested (primary and chemical)
Annapolis, Md.	Digested primary
Kokomo, Ind.	Digested primary
Ann Arbor, Mich.	Digested (primary and activated)
Chicago, Ill.	Raw primary and activated
St. Charles, Ill.	Chemically precipitated
Auburn, N. Y.	Raw primary and chemically precipitated

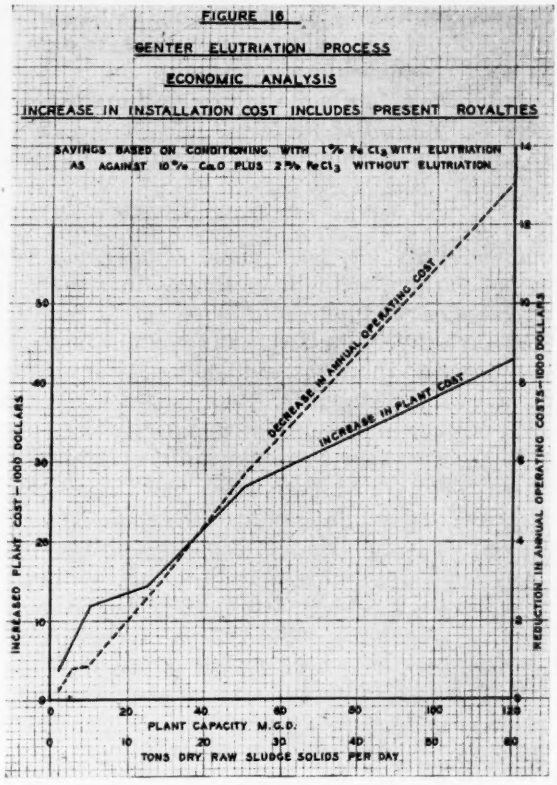


FIGURE 16
CENTER ELUTRIATION PROCESS
ECONOMIC ANALYSIS
INCREASE IN INSTALLATION COST INCLUDES PRESENT ROYALTIES
SAVINGS BASED ON CONDITIONING WITH 1% Fe Cl3 WITH ELUTRIATION AS AGAINST 10% CaO PLUS 2% FeCl3 WITHOUT ELUTRIATION
DECREASE IN ANNUAL OPERATING COST
INCREASE IN PLANT COST
INCREASED PLANT COST — 1000 DOLLARS
REDUCTION IN ANNUAL OPERATING COSTS — 1000 DOLLARS
PLANT CAPACITY M.G.D.
TONS DRY RAW SLUDGE SOLIDS PER DAY

Sludge incineration was first successfully demonstrated by the Chicago Sanitary District in 1932. At the present time the only sludge incinerator in operation is at Dearborn, Michigan. Other units under construction or under contract are those for Chicago, Kokomo and Auburn on the types of sludge as noted above.

Trends

The large number of vacuum filter installations operating or under contract indicates a definite trend toward this method of sludge dewatering as against sand drying beds. To date, not enough incinerator plants have been contracted for to indicate exactly where they will fit in the field of sewage treatment. From this cost analysis, it appears that their greatest field will be in the range of the large plants, specifically above 25 m.g.d., and in the smaller plants where no sludge dumping facilities are available and where there is no local market for the sale of sludge as a fertilizer. Local factors will exert a considerable influence on the method of treatment adopted in each case, but digested sludge incineration appears to be more desirable than raw sludge incineration, with a distinct tendency toward short-time diges-

tion periods. An exception is the case of activated sludge treatment, where incineration of the digested primary and the undigested activated sludge may be more economical.

Where there is a considerable local market for the sale of sludge as a fertilizer, present types of incinerators may be modified so that they can be used as dryers or as combination dryers and incinerators.

Summary and Conclusions

1. An economic study has been made comparing installation and operating costs of various methods of sludge disposal where primary, trickling filter, chemical and activated sludge treatment are used.

2. Peak loads are a very important factor and must be taken into consideration, especially where raw sludges are filtered and incinerated. In such cases, a two-day sludge storage or thickening period is advisable, and excess filter and incinerator capacity may have to be furnished to handle three to four times the daily average dry solids load.

3. Installation costs are highest where peak loads of 375 per cent of the daily average dry solids load are assumed.

4. For all plant sizes, raw sludge incineration first costs using only 125 per cent peak loads are higher than those for digested sludge filtration without incineration. They are slightly lower, however, in the case of plants of over 15 m.g.d. capacity, than where digested sludge is filtered and incinerated or where mixed digested primary and undigested activated sludge is filtered and incinerated.

5. Installation costs are lowest where all of the sludge is digested prior to dewatering on vacuum filters. An exception is the case of activated sludge treatment, where filtration of the combined digested primary and thickened undigested activated sludges gives the lowest first cost.

6. Operating costs of raw sludge incineration plants are highest even where only 125 per cent peak loads are assumed.

7. Operating costs are lowest for plants of less than 10 m.g.d. capacity where open sand drying beds are used. In general, for plants of over 25 m.g.d. capacity the costs of digested sludge filtration or filtration with incineration are lowest.

8. In the case of activated sludge treatment the desirable procedure from an operating cost standpoint is to combine the digested primary and the thickened undigested activated sludges prior to filtration or filtration with incineration.

9. Operating costs may be reduced considerably in the case of digested sludge handling by resorting to shorter digestion periods (20 days) and by using the elutriation or sludge washing process as developed by Genter.

10. Present trends appear to be toward vacuum filtration of sludges in the smaller plants, with a possibility of drying the sludge cake for local marketing as a fertilizer. In the larger plants, sludge incineration will find a more widespread application.

11. The findings and conclusions presented here are based on the exact conditions and costs noted in this paper. They are not intended to cover all conditions. In general, each problem must be analyzed on its own merits, taking into consideration the various influencing local factors.

References

1. R. A. Allton, Private communication.
2. W. B. Walraven, "Power Production from Sludge Gas at Springfield, Ill.," *Water Works and Sewerage*, May, 1933.
3. M. B. Owen, "Sludge Incineration at Dearborn," *Water Works and Sewerage*, August, 1935
4. C. E. Keefer, "The Vacuum Filtration of Elutriated Sludge," JOURNAL, September, 1934.
5. A. L. Genter, Private communication.

Discussion

By A. L. Genter

Chemical and Mechanical Engineer, Baltimore, Md.

Dr. Fischer's paper on "The Economics of Various Methods of Sludge Disposal" is, in my opinion, an excellent presentation of the fundamental features influencing the economic disposal of sewage sludges. It presents an analysis containing most of the essential economic constituents which must ultimately enter into the reverse of any analysis, *i.e.* the design and synthesis of any type of plant involving the disposal of sewage sludge.

Naturally such a paper cannot present economic values governing all localities throughout this or any other country, and Dr. Fischer's paper is not intended as such. However, there are certain factors relative to sludge incineration that have universal application. One of these is the inert material or ash present in any sludge being incinerated.

The more inert material, in the form of chemicals, added to any sludge in order to render it filterable, the less the fuel value of the sludge becomes and the more extraneous fuel has to be added for final incineration. All dried sludges ready for incineration naturally contain large quantities of noncombustible material. Dr. Fischer indicates the importance of considering the addition of further noncombustibles to sludges, in the form of chemical conditioners used for rendering such sludges dewaterable on vacuum filters. My discussion is intended to place more emphasis on this particular point and to indicate where further definite economies are to be expected in sludge disposal.

In incinerating raw and digested sludges that have been subjected to precipitation with lime and ferric salts and without elutriation, ash or inert material is actually added to the sludges in relatively large amounts. That these chemicals, especially lime, greatly increase the volume and weight of any sludge has been known for some time. The figures given by Dr. Fischer for the approximate increase are quite conservative. Any figures showing the addition of lime in per cent CaO on

solids present, neglect the other inert materials such as silica, magnesium, alumina and incidental or combined moisture common to most commercial grades of lime. In fact a great deal of lime is added in the hydrated form and enters into the precipitating reaction with ferric salts as the hydrate. At temperatures resulting during sludge incineration it is reasonable to assume that considerable heat is consumed in dehydrating the final chemical compounds and producing oxides and possibly silicates.

That every per cent of added ash in the form of lime and other inert compounds reduces the net amount of combustible substance in any sludge, just as does moisture, is beyond question. The presence of added iron also distinctly tends to lower the fusing point of all materials forming silicates and clinker when burning sludge, just as it does in burning ordinary fuels.

It is certain that the use of lime can be entirely eliminated by elutriating the sludge before incineration. It is equally certain that the amounts of ferric salts, ordinarily added for coagulation purposes, can likewise be materially diminished by sludge elutriation. Such treatment should therefore definitely diminish the constant daily costs of (1) sludge dewatering and (2) sludge incineration. In any ultimate comparative analysis of sludge disposal methods involving incineration, the elutriation process should be credited, not only with savings in the costs of coagulants, but likewise with fuel savings due to a material reduction of ash deliberately added for sludge conditioning.

This statement also applies to the dewatering and incineration of raw sludge, especially where plant effluent from secondary treatment, *i.e.* trickling filters or activation, is available for elutriating primary raw sludge. It is erroneous to believe that elutriation is practical only for digested sludges, especially with primary sludges held in storage for a day or so before dewatering. The published and unpublished data on elutriation of such sludges show that lime is not necessary for final dewatering and a large percentage of the ferric chloride ordinarily used can be saved. It is admitted that no large increase in filter yields can be effected by elutriation of raw sludges, as is the case with elutriation of digested sludges, but this is of minor importance when considering the reduction in coagulant consumption.

As all published data relate to single-stage elutriation, more material savings result from continuous counter-current elutriation. Unpublished data clearly show this to be true for digested and raw sludges. In treating mixtures of digested and primary raw or digested and activated sludges the best practice will probably be that involving elutriation of the digested portion only and mixing the elutriated portion with the unelutriated portion. Using counter-current elutriation on the digested portion should result in a sludge mixture that can be readily dewatered on vacuum filters with about one per cent ferric chloride on dry solids present. This is especially true when continuous heated digestion tanks are employed.

The equipment subject to most depreciation in all sludge disposal

schemes involving mechanical devices for dewatering and incineration is that involving filtration, drying and incineration. Hence any process which definitely reduces the magnitude and consequent cost and depreciation of this equipment is of prime importance in any analysis of sludge disposal costs.

That the dewatering and incineration of raw sludge, with or without elutriation, involves the use of larger dewatering and incineration units is aptly emphasized by Dr. Fischer. This undeniable fact, together with others, seems to indicate clearly that the most economic means of disposing of raw sludge, in plants of the sizes covered by Dr. Fischer's survey, is by digestion, elutriation and dewatering on vacuum filters, either with or without final drying and incineration.

It should be emphasized, however, that with modern separate digestion tanks followed by elutriation and vacuum filtration of the digested sludge, it is no longer necessary to continue sludge digestion to the point necessary for dewatering on sand beds. Unpublished research data show such practice to be economically useless. Sludges taken from the new Dorr digesters at Baltimore, when the volatile matter is around 67 per cent, show remarkable coagulant savings when subjected to counter-current elutriation. The indications of all these data clearly point to the fact that just as mechanical dewatering makes sludge disposal independent of large sand bed areas and season, as well as relatively extensive time duration, it can also materially decrease digestion time and space. This definite possibility of reducing the cost of digestion equipment clearly points to further material savings in favor of Dr. Fischer's arguments presented in his excellent survey.

POLICIES AND PROGRESS IN SEWAGE TREATMENT IN NEW YORK STATE *

By Earl Devendorf

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Since 1931 members of the New York State Sewage Works Association have played a prominent and important part in the promotion, planning and supervision of sewer and sewage treatment plant construction as a means of relief of the large army of unemployed.

Although much has been written on the subject and all authorities have been in general agreement as to the merits of sewer and sewage treatment plant construction from the standpoint of permanent value to the country, so far as the writer is aware, no one has presented a record of the accomplishments in this field in New York State. It would seem fitting, therefore, to present a review of the record of accomplishments in the field of sewer and sewage treatment plant construction, in particular under the various federal and state agencies created to assist local authorities in initiating work relief projects with federal and state aid.

The tables presented below give a record of the sewerage construction under P.W.A., C.W.A., T.E.R.A., and W.P.A. in order named.

P.W.A.

The accomplishments in sewer and sewage treatment projects under the P.W.A. in New York State are summarized in Tables I and II. These data were obtained from the office of Mr. Arthur S. Tuttle, Acting State Director of P.W.A.

Table I.—*Old P.W.A. Program*

Types of Projects	Number	Cost	Per Cent of Total	Contracts Awarded up to October 25, 1935	Per Cent Awarded
Water works	35	$ 5,780,000	4.7	4,160,000	72
Sewage and sewage disposal	33	10,700,000	8.7	8,550,000	80
Total—all types of projects		$123,000,000			

New P.W.A. Program

Types of Projects	Number	Cost	Per Cent of Total
Water works	18	$ 1,380,000	1.12
Sewage and sewage disposal	25	48,000,000	39.0
Total—all types of projects		$123,500,000	

* Presented Before the Eighth Annual Meeting of the New York State Sewage Works Association, Hotel Astor, New York City, Wednesday, January 15, 1936.

From Table I it is readily apparent that while sewerage and sewage treatment projects comprised but a small proportion of the first, or 1933 P.W.A. Program, in the 1935 Program, their cost comprised nearly four times that of the 1933 Program, although the number of projects was slightly less in the 1935 than in the 1933 Program. This is accounted for by the inclusion of a number of projects of great magnitude and cost in the 1935 Program, notably the Wards Island New York City, Buffalo, Elmira, and Auburn projects. The small percentage of sewer and sewage treatment projects in the 1933 Program is also in part due to the time required by municipal authorities to authorize and have surveys and plans prepared for such construction projects. Included among these sewer and sewage treatment works projects are many improvements and enlargements that have long been recommended by the State Department of Health.

TABLE II.—*Sewerage*

1933 P.W.A. Projects

Place	Description	Cost
Canajoharie	Sewage Treatment Works	$ 55,000
Malone	Sewage Treatment Works	33,000
Belgrave	Sewerage and Treatment Works	125,000
Rensselaer	Sewer Extensions	19,000
Mt. Morris	Improvements to Sewage Treatment Works	15,000
Suffern	Sewer System and Treatment Plant	232,600
Hastings	Connection with Saw Mill Trunk Sewer	19,000
Walden	Sewer System and Treatment Plant	319,900
Penn Yan	Modification to Sewage Treatment Works	41,800
Canton	Extensions and Treatment Plant	50,000
Hamburg	Additions to Sewage Treatment Plant	57,000
Geneva	Sewers and Sewage Treatment Plant	272,600
Cedarhurst	Sewers and Sewage Treatment Plant	642,500
Lloyd	Sewers and Sewage Treatment Plant	142,000
Pleasantville	Extensions	70,000
Woodridge	Sewer System and Treatment Plant	140,000
No. Yonkers	Trunk Sewer	$ 1,378,000
Rochester	Sewage Discharge	660,000
Yonkers	Extensions	702,600
Great Neck	Sewerage and Sewage Treatment	569,100
Elmsford	Sewer System	331,500
White Plains	Sewer Extensions	295,000
White Plains	Storm Sewers	255,000
Scarsdale	Sewers	74,000
Ardsley	Sewer System	222,435
West Long Beach	Sewers and Treatment Plant	42,000
Greenburg	Sewer System	230,000
West Haverstraw	Sewers and Treatment Plant	150,000
New York City	Coney Island Sewage Treatment Plant	1,900,000
Buffalo	Filmore-Lovejoy Storm Drain	1,148,370
Authorized not yet started		
Freeport	Treatment Plant Improvement	$ 106,800

TABLE II.—*Continued*

1935 P.W.A. Projects

Place	Description	Cost
New York City	Wards Island Sewage Treatment Plant	$25,000,000
New Castle	Sewerage System	30,000
Buffalo	Trunk Sewers, Treatment Plant, Etc.	15,000,000
Auburn	Sewers	800,000
Herkimer	Sewage Treatment Plant	75,000
Cornwall-on-Hudson	Sewer System	188,502
Niagara Falls	Treatment Plant	2,200,000
Yonkers	Sewers	310,965
Maybrook	Sewer System	65,000
Riverhead Sewer D.	Sewer System	167,749
Pittsford	Sewage Treatment Plant	100,215
Ballston Spa	Modification of Sewage Treatment Plant	81,000
Geneseo	Sewage Treatment	119,465
Watkins Glen	Sewage Treatment	60,000
Dickinson, Tn.	Sewer System	60,000
Endicott	Sewers	52,000
Newfane	Sewers and Treatment Plant	146,211
Elmira	Sewers	932,000
Highland Falls	Sewer System and Treatment Plant	270,572
New Castle, Westchester County	Chappaqua Sewers	350,000
Sanitary Sewer	Blind Brook project	383,150
	Mt. Pleasant project	1,050,000

T.E.R.A.

Mr. James P. Lee, Director of the Project Division of T.E.R.A. has compiled the following information regarding sewer and sewage treatment plant construction. Shortly after beginning operation the T.E.R.A. organized an engineering personnel with district engineers appointed throughout various sections of New York State, to promote and supervise the carrying out of construction projects. The effect of such engineering supervision was noteworthy and resulted not only in an improvement in the types of projects undertaken but also in improved efficiency in the construction methods employed.

Table III shows a summation of work projects undertaken by the

TABLE III.—*Projects Undertaken by T.E.R.A. in New York State November 1, 1931 to November 20, 1933*

Classification	Number of Projects	Total Cost	% Total Cost	Relief Wages	Other Costs	Per Cent		Man-Days of Work Provided
						Wages	Other	
All projects	4,866	$113,901,948.29	100	$95,649,911.72	$18,252,036.57	84	16	23,467,580
* Sanitation	697	11,049,675.59	9.7	8,529,750.40	2,519,925.19	77	23	2,141,560
Water supply	331	3,929,288.53	3.5	2,693,613.78	1,235,674.75	69	31	605,730

This table covers work done prior to the C.W.A.

* Sanitary and storm sewers, sewage disposal plants, incinerators, etc.

T.E.R.A. in New York State, beginning with the formation of the T.E.R.A. in November, 1931, and extending for two years to Novem-

ber, 1933, covering the work accomplished prior to C.W.A. Of a total of about $114,000,000 only $11,000,000 went for construction of sanition projects, including sanitary and storm sewers, sewage treatment plants, incinerators, etc., equivalent to a little less than 10 per cent of the total of all types of construction.

Table IV gives a classification of expenditures undertaken under

TABLE IV.—*Sewerage and Sewage Treatment Projects Undertaken Under C.W.A. in New York State November 20, 1933 to March 31, 1934*

Class of Work	Number of Projects	Man-Hours of Work Performed	Wages and Salaries	Teams, Trucks and Equipment	Materials	Other Costs	Total Costs
New construction of sewers, drainage and sanitation, sewage disposal plants, incinerators	321	9,935,249	$6,055,832.73	$310,612.53	$2,110,803.83	$84,342.32	$8,561,591.41
Repair and maintenance of sewers, drainage, etc.	99	1,392,473	829,395.96	36,023.15	176,580.32	4,138.77	1,046,138.20

* Total expenditures under C.W.A. for all classifications of work performed are not available at this time.

C.W.A. and covers the period from November 20, 1933 to March 31, 1934. The total expenditures under this program for all classification of work are not available at this time.

Table V gives a tabulation of work relief carried out under the

TABLE V.—*Sewerage and Sewage Treatment Projects Approved by T.E.R.A. in New York State April 1, 1934 to July 1, 1935*

Class of Work or Service	No. of Projects or Jobs	Man-Hours of Work Performed	Wages and Salaries	Teams, Trucks and Equipment	Materials	Other Costs	Total Costs	% Total Cost
Total all projects	16,188	545,999,424	$322,543,547	$27,572,940	$61,981,578	$5,939,553	$418,037,618	100
New construction of sewers, drainage and sanitation, sewage disposal plants, incinerators	934	29,127,919	16,119,534	2,017,476	4,982,917	480,982	23,600,909	5.65
Repair and maintenance of sewers, drainage, etc.	158	6,003,759	1,972,724	187,970	154,977	16,018	2,331,689	0.56

T.E.R.A. after the close of C.W.A. program, from April 1, 1934, to July 1, 1935. Over 16,000 work relief projects were undertaken, at a total cost of $418,000,000. Of this amount, 834 new sanitation works construction projects were completed, at a total cost of slightly over $23,500,000, amounting to a little more than 5½ per cent of the total. Only 158 repair and maintenance sanitation projects were completed, at a cost of a little over $2,300,000, amounting to a little under ½ per cent of the total.

TABLE VI.—*To July 1, 1935, the Following Sewerage and Sewage Treatment Work has been Accomplished under T.E.R.A.**

Miles of sanitary sewers constructed	273
Miles of storm sewers constructed	233
Miles of sewers cleaned	27
Number of cesspools constructed	77
Number of sanitary privies constructed	15
Number of sewage disposal plants constructed (including septic tanks)	23
Number of sewage disposal plants improved and repaired	25

* Some of this work was started under C.W.A. but most of it has been accomplished after April 1, 1934.

Table VI gives a summary of sanitary work carried out under T.E.R.A. during the period covered under Table V, namely from the close of C.W.A. to July 1, 1935. As indicated in the table 273 miles of sanitary sewers and 233 miles of storm water sewers were constructed; 27 miles of sewers were cleaned; 23 sewage treatment plants were constructed; and 25 treatment plants were improved and repaired.

It is hardly possible to discuss the details of individual projects, but a few outstanding projects have been selected and described below, as representative of various types of projects which have been undertaken and completed under the T.E.R.A.

SANITARY SEWERS

A project was begun May 21, 1934, for the purpose of connecting and extending the various existing sanitary sewers into one complete system in the Mamaroneck Valley.

The work, sponsored by the Westchester County Sanitary Sewer Commission, consisted of the installation of 14-in. cast iron and 24-in. reinforced concrete pipe, the building of 16 manholes, and the trenching, tunneling and backfiilling required to install the pipe lines at the given grades.

Of the 4,049 ft. of pipe laid, 1,665 ft. were laid in tunnels where open trench work was impracticable or too costly. This necessitated the sinking of five access shafts, averaging 27 ft. in depth. While most of the tunneling was through solid rock, it was necessary to shore and timber certain sections, and to use liner plate wherever soft muddy soil was encountered. The open cut work required depths ranging from 6 to 33 ft.; with an average of 20 feet. An elaborate system of shoring was employed where street openings were made, to protect both the adjoining properties and the men working in the trenches. Installation of the sewer also involved the removal and replacement of 8,498 sq. ft. of concrete pavement and 17,469 sq. ft. of macadam road; earth and rock excavation amounted to 7,458 and 1,572 cu. yd., respectively; backfill totaled 6,930 cu. yd.; also 673 lineal feet of double car tracks were removed.

The entire project, completed September 28, 1935, cost $114,957.42, the wages and salaries accounting for $79,296 of this total. The work-

ing force, averaging 85 men on a two shift weekly basis, were given 102,200 man-hours of work.

The installation is of direct benefit to the residents affected by the entire drainage system, and has been completed at a unit cost comparable to contract work.

Storm Sewers

The City of Buffalo's recently completed project for the Germania Street Storm Water Drain is outstanding not only from the point of view of social utility but as an engineering achievement. This project, begun in July, 1934, has transformed a wide area of swamp and semi-swamp land into potentially valuable industrial property and has relieved from seasonal floods a densely settled area of small houses covering nearly 40 city blocks. Altogether, about 1,075 acres in South Buffalo are benefited. The section is one in which considerable future development is indicated.

The old drain line serving this area was totally inadequate, and in every rainy season a vast overflow of storm water and diluted sewage drained off through open ditches and culverts, or followed completely exposed natural channels. For years, homes have suffered annual floods, cellars have been inundated and streets ruined.

The Germania Street project involved the laying of twin concrete drain pipes, tapering from 78-in. widths in the main sections of the line to 60-in. widths as they reached higher ground. The double lines extended a distance of 2 1/3 miles.

These new installations carry out portions of a major sewage and drainage program set up after an engineering survey made several years ago. The program has been subject to nearly a decade of debate and delay. Although various groups of citizens had constantly fought against the unsanitary and destructive conditions, large-scale operations were first made possible through the efforts of the local work bureau.

Most formidable among the many physical obstacles to construction was the prevailing high ground water level. Water was frequently found within one foot of the surface, and it never ranged lower than nine feet. This was overcome by using the Moretrench Wellpoint System, which consists of a number of well points driven to a depth below invert grade and attached to a header leading to a pump. The pump sucks the water from the well points into the header and discharges it for final disposal. In some sections, after 26 hours of pumping at a rate of 192,000 gal. per. hr., the water was reduced to a level of 23 ft., enabling excavation to commence within the sheeted trench with absolutely no interference due to flooding. All excavation was done by hand; sometimes the material was passed up three or four stages, depending on the depth of the trench, before reaching the surface. When grades were reached, a 6-in. reinforced concrete mat was laid to carry the twin pipes; after the joints were sealed with a cold asphalt com-

pound, concrete was poured over the pipes to spring line elevation, thus insuring permanent alignment.

Soil conditions were everywhere extremely bad. On one section, designated as the Germania Outlet, steel sheet piling was necessary for the first 400 feet. The invert slab consisted of a 12-in. bar-reinforced concrete mat, supported on wooden piles driven 35 ft. to rock. The Moretrench System was operated here 24 hr. per day and, although the sub-grade of this section was 8 ft. below mean water level of the Buffalo River, the men were able to work without boots.

The Abbott Road and Boone Street Outlet—an addition to the original project—is also to carry drainage from the new lines to the river, a distance of 772 feet. A main connecting chamber and a secondary chamber, which takes up the overflow from existing lines, were constructed here of concrete. The backfill in this section was mixed with concrete in the ratio 1 to 10 to prevent the lines from settling. At the point of discharge into the river it was necessary to erect a concrete headrail 32 ft. long, 20 ft. high and tapering from 14 ft. in thickness at the base to 2½ ft. at the top. To support this wall, wood piling was driven to a 40-ft. sustaining level. Since this section cut across the path of heavy highway travel a temporary road, 200 ft. long, was built to divert traffic. As in the case of the main line, existing sewers had to be dug and relocated.

The original project, estimated at $657,555.70, was completed for $372,062, of which $178,879 was for labor. Excavation totaled 50,000 cubic yards, backfill 20,000 cubic yards, brick paving 1,800 square yards, asphalt paving 150 square yards and concrete sidewalks 20,000 square feet. The Abbott Road Outlet, referred to above, has cost $68,472 for labor and $82,130 for materials and equipment. A second extension, the Interceptor Section, has been completed at a cost of $36,583, including $19,692 for labor.

Worthy of note are the smoothness with which operations were conducted and the excellent morale of the workers. A reasonable but determined discipline was maintained, and the work was carried through with miscellaneous relief labor at nearly the same level of efficiency that a private contractor could have secured with trained men. These factors, together with the low unit costs involved, were due in great measure to the supervisor of the project, a member of the local Relief Board and a veteran of long experience in such work. This official, who gave unstintingly of his time and efforts, served without pay.

Besides the fact that the Gowanda Street project provided about 470,000 man-hours of work for an average of 579 men, it can be said that it was perhaps the best understood and appreciated of all work relief projects by the people of Buffalo. Public reaction could not have been otherwise than highly favorable in view of the assured and long needed relief from intolerable conditions.

Sewage Disposal Plants

The problem of sewage disposal is one that has come more and more to the foreground in recent years. Unfortunately, because of their lack of finances, municipalities have not always been able to conform to the State Department of Health requirements concerning raw sewage disposal. To many such communities the work relief program was the medium through which they accomplished permanent constructive undertakings important to the health of the community.

An excellent example is the City of Beacon's recently completed sewage disposal plant on Fishkill Creek, a tributary stream of the Hudson River. The old plant, abandoned several years previously, provided a convenient site for the new installation. To determine future needs, a graph of population growth was drawn, which indicated that the population of the district, served by the connecting sewer system, would reach 7,000 by the year 1960.

The city had plans drafted by a firm of consulting engineers, who assigned a resident engineer, expert in this type of work, to supervise construction.

After the plans had been approved by the State Department of Health, work was started July 6, 1934, with excavation for the clarifiers. The method of sewage treatment decided upon embodied the use of mechanical clarifiers with digestion tanks for the sludge and sludge drying beds. Two concrete, mechanically cleaned, circular clarifying tanks, with center feed, were built to grade 8.5 ft. high, with diameters of 26 feet. After excavation had been completed for the digestion tanks, also measuring 26 ft. in diameter, forms were set and concrete poured for the walls which are 13.5 ft. high. The necessary piping and equipment for the collection and burning of gas and recirculation of hot water for heating the digestion tanks in cold weather were included in the project.

The sludge drying beds, laid out in a series of four, cover an area of 7,000 square feet. Additional excavation was necessary to provide adequate depth for the gravel and sand fill, and also for the construction of the concrete walls lining the beds. One-half of the drying area, or 3,500 sq. ft., is glass enclosed. The sludge bed distribution system consists of stationary castiron pipes with deflector nozzles.

Other related work included the construction of a pump and boiler house, 20 by 30 ft., and a screen house, 17 by 30 feet. To connect the plant with the sewer system, 175 ft. of 24-in. vitrified tile pipe was laid, while 1,250 ft. of 2-in. line forms a similar connection with the water system. Intake and drain lines were placed at the plant. A sludge control manhole was constructed and the necessary mechanical equipment for the operation of the plant installed. During the course of construction, plans were revised to make provision for doubling the capacity of the plant at some future date. This necessitated moving the contact beds one section south to allow room for an additional clarifier tank. The change only involved a slight amount of excavation at

the sludge control manhole. The forms used on concrete work were removed and stored for future use in the construction of a plant on the Hudson River, to serve that part of the city not connected with the new system.

The project, completed June 20, 1935, provided approximately 39,000 man-hours of work to an average force of 50 men. Total costs of $57,569 were distributed as follows: wages and salaries, $29,222; equipment, $2,037; material, $26,137; other costs, $173.

This undertaking, requiring a high degree of technical skill, was completed to the entire satisfaction of all concerned. Engineers and members of the New York State Sewage Works Association, who inspected the plant, commented on the excellence of the work performed, and the project was watched with interest by nearby municipalities. The city of Beacon, in acquiring one of the most modern sewage disposal plants in the state, leads the way for other cities, and brings nearer the day when the present widespread pollution of the Hudson River will be a thing of the past.

W.P.A.

Since the W.P.A. started operation only December 1, 1935, it is too early to present any summary of its accomplishments on sanitation projects, including sewers and sewage treatment plant construction. Among those projects in New York State which have received presidential approval are included some 652 in sanitation, including storm and sanitary sewers and sewage treatment plant projects with a total allotment of $38,600,000. Of these, 436 with a federal allotment of $18,800,000 have been released for operation as of December 30, 1935. It is probable that the total cost of this project will be about $23,000,000.

Summary

The tabulations given above indicate the vast amount of public funds that have been expended in New York State during the past four years of the depression as a means of relief of unemployment. Under P.W.A. some $245,000,000 in New York State have been alloted for public works construction. Under T.E.R.A. and C.W.A. programs nearly $750,000,000 have been expended. We cannot predict how much longer it will be necessary to carry on public works projects as a means of relief of unemployment. All engineers and public works officials should have plans prepared for needed sewer and sewage treatment plant construction, in order to be able to initiate the work without delay.

All public health officials, both national and state, have for years endeavored to stress the importance of providing for the construction of sewage treatment works, in order to eliminate stream pollution. When it is realized that in New York State over three-fourths of the population is furnished with public water supplies derived from surface water sources the importance of controlling stream pollution becomes immediately apparent. Certain of our streams in New York

State which are sources of public water supply are at times polluted beyond the safe limit to insure the production of waters of safe sanitary quality, even though the most complete water purification plants are in use and operated under expert technical control.

Under the National Resources Committee (Formerly National Resources Board) State Planning Boards were organized in 46 states for the purpose of coördinating and planning needed public works projects from the national, state, and local viewpoint. Leading engineers of the country are represented on these boards and have stressed the importance of stream pollution prevention and made definite recommendations for including sewage treatment plant construction in future public works programs. It seems not only logical but essential that the recommendations of these organizations for sewage treatment plant construction should be given careful consideration and included as a major item in planning future works programs with federal or state aid.

Stream Pollution

MEASURES OF NATURAL OXIDATION IN POLLUTED STREAMS. III. AN EXPERIMENTAL STUDY OF ATMOSPHERIC REAERATION UNDER STREAM-FLOW CONDITIONS

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The atmospheric reaeration of natural bodies of water has been a subject of interest and study to sanitary engineers and chemists for many years past, owing to the important relation which it bears to the promotion of normal aquatic life in all waters and to the maintenance of self-purification in waters polluted by sewage and industrial wastes. Although the general laws underlying this phenomenon are well known, the extent to which it is governed by certain physical conditions surrounding natural watercourses, such as temperature, depth, and degree of agitation or turbulence has been less clearly defined by specific observational data. In view of the need for data of this character, it has appeared desirable to present in the following paper the results of some experimental measurements of reaeration made in artificial channels under flow conditions approaching those of small natural streams.

The measurements in question were made during portions of the years 1932–35, at the Cincinnati Stream Pollution Investigations Station of the U. S. Public Health Service, in connection with some experimental observations, now in progress, on the rates at which sewage sludge deposits are oxidized under artificial stream-flow conditions similar to those found in polluted natural watercourses. In these experiments, the most direct method of determining the rate of sludge oxidation has been to correct the total amount of oxygen absorbed by the supernatant water from the atmosphere during a given period of time for the observed change in the dissolved oxygen content of the water during the same period. In order to apply this method, it was necessary to predetermine, for the same channels as used in the sludge oxidation experiments, the rates at which streams of deaerated water having no appreciable oxygen demand absorbed atmospheric oxygen when flowing through them at temperatures, depths and velocities of flow similar to those used in these experiments. By amplifying the scope of these preliminary reaeration measurements, it was possible to obtain results covering a fairly wide range of conditions.

For the purpose of these observations, three different artificial channels have been used. The first is a flume 1080 ft. long, consisting of 12 sections, each 90 ft. long, running parallel to each other and connected together in series by means of 180° bends. The flow of water is

continuous through this flume, its rate being controlled by an orifice at the inlet and its depth by adjusting the height of an overflow pipe at the outlet. The flume is 6 in. deep throughout its length, the first 90-ft. section being 5 in. wide and the remaining 11 sections, 2 in. in width. It is constructed of galvanized sheet-iron and was lined with a paraffin coating for the measurements herein recorded, in order to minimize any errors of measurement due to oxidizing of the metal by the oxygen contained in the water.

The second and third channels are of a different type, being practically identical with each other except for their dimensions, one being a small scale model of the other. Each one of these channels is arranged in parallel sections, connected in such a manner as to form a continuous loop, through which water is recirculated by means of a motor driven boat propeller, the speed of which can be varied over a wide range by reducing gears and different combinations of pulleys. The smaller channel, originally designed by Special Expert W. C. Purdy for some biological experiments, is of approximately the same cross-sectional scale as the continuous-flow channel above described, being 6 in. deep and 3 in. wide. The larger unit is constructed of heavy sheet copper, in a tank 10 ft. long and 3 ft. wide, the channel being 18 in. deep and 6 in. wide throughout its total length, which is 58.4 ft., including bends.

A. Continuous-Flow Channel Experiments

Observations in the continuous-flow channel were carried out during two periods, the first extending from November, 1932 to April, 1933, and the second from September, 1933 to January, 1934. Prior to beginning these observations, an attempt had been made to measure rates of reaeration in a series of channels previously used in connection with some other experiments.* As these channels were originally connected by flexible hose, through overflow pipes, it was not practicable to operate them without entraining variable amounts of air in the water passing through these overflow pipes. The system was accordingly reconstructed into a series of 12 parallel sections, with open-end connections, forming a continuous flume as previously described.

In order to provide for continuous deaeration of the tap water passing into the channel, two pitch-lined pipe columns containing iron filings were installed in parallel with each other and both in series with the tap water supply line leading to the channel. Only one of these two deaerating columns was usually operated at any time, the second being held in reserve and placed in service when the other was disconnected for acid treatment to remove the accumulated iron oxide from the surfaces of the filings. This apparatus was a very effective means of deaerating water continuously, as the effluent ordinarily entered the channel with a dissolved oxygen content less than 0.5 p.p.m.

For sampling purposes, eight stations were fixed along the channel, each being designated by its section number beginning with the entry

* Hoskins, J. K., "Bacterial Purification Rates in Polluted Water." *Amer. Jour. Hygiene*, **21**, 2, 280–301 (March, 1935).

section, and by its distance in feet from the entry end of that section. The entrance station, designated as 1–5, was located in the first section of the channel 5 ft. from the point of inflow. The last station, 12–90, was located in the twelfth and last section at its outlet end. The other stations, located at intermediate points, were designated as 1–90, 2–90, 4–90, 6–90, 8–90 and 10–90, their locations being at the outlet ends of the sections indicated.

The period of the observations covered 213 test days, with two complete sets of sample collections on each day at all of the stations above indicated. Each sample was taken by means of a siphon at mid-depth, its temperature recorded and the reagents for the Winkler test added immediately after collection. Preliminary tests made on samples collected at surface, mid-depth and bottom points and also integrated from top to bottom had shown that the mid-depth sample was most nearly representative of the average cross-section of the stream. In collecting each sample, the bottle was filled slowly and its entire contents displaced before inserting the glass stopper and removing the siphon.

Because of restrictions in the capacity of the deaerator with continuous flow, it was necessary to limit the rate of flow of water through the channel to a maximum of 1.5 gallons per minute. In order to provide a sufficient range of flow variation, three different rates were used, namely, 0.5, 0.75 and 1.5 gallons per minute. At each rate of discharge, several measurements were made with flow depths of 2, 3, 4 and 5 inches, respectively, each measurement being planned so as to embrace a different range of water temperatures. The major difficulty met in the tests was inability to control the temperature of the channel stream throughout a given day, as the channel was located in a glass-enclosed "green-house" which absorbed heat from the sun and the outside atmosphere. In the summer, the temperature inside the enclosure increased rapidly during the day and the water flowing in the channel became progressively warmer from early morning to late afternoon. On extremely cold mid-winter days, this trend was reversed. In both cases lag in the readjustment of the dissolved oxygen saturation values occurred in the stream between inlet and outlet, and this sometimes introduced a slight error into the calculation of rates of oxygen absorption based on saturation deficiencies. The most favorable periods for the observations were in the spring and autumn, when temperatures inside and outside the channel enclosures were more nearly equalized and on occasional days in summer and winter when similar conditions prevailed. As far as practicable, the observations were confined to these more favorable periods, though it was not always feasible to do so.

In order to show a typical set of results from an individual experiment, Table I has been prepared from the observations made during a single day, with a mean water depth of 4 in. in the channel and a rate of discharge of 3/4 gal. per min., giving an average rate of flow of 1.6 ft. per min. from the inlet to the outlet of the channel.

In this table it will be noted that the dissolved oxygen content of the water entering the channel (Sta. 1–5) was 0.23 p.p.m. or 2 per cent of

TABLE I.—*Results of Observations Obtained from a Typical Experiment in the Continuous-flow Channel, with Mean Depth = 4 Inches and Discharge = 0.75 Gal. per Minute*

Station	Water Temp. ° C.	Dissolved Oxygen Content			Reaeration Rate, from Sta. 1–5, as:			
		Obs'd P.p.m.	Per Cent Sat'n	Sat. Deficit P.p.m.	k_2 (Per day)	f (Per min.)	r_t	r_o
							Gms./sq.m./day	
1–5	10.0	0.23	2.0	11.10				
1–90	10.0	1.07	9.4	10.26	0.42	.0068	1.06	1.12
2–90	10.0	1.37	12.2	9.96	.40	.0065	1.01	1.10
4–90	9.7	1.98	17.3	9.43	.38	.0062	.96	1.07
6–90	9.5	2.64	23.1	8.82	.38	.0062	.96	1.10
8–90	9.5	3.06	26.7	8.40	.37	.0060	.89	1.05
10–90	9.5	3.77	32.7	7.69	.40	.0065	.91	1.11
12–90	9.5	4.24	36.0	7.22	.40	.0065	.88	1.10

saturation, increasing from this amount to 4.24 p.p.m., or 36 per cent of saturation at the outlet (Sta. 12–90). In the right-hand section of the table the rates of reaeration observed from the entrance station to each successive downstream point have been expressed in four different ways, all having been described in the second paper * of this series.

The coefficient (k_2), as given, is a measure of the proportionate rate of absorption per unit of water volume per day. Corresponding rates per hour would be indicated by figures 1/24 of those given. The coefficient (f), which is the same as Adeney's constant, defines the proportionate rate of oxygen absorption per square centimeter of water surface per minute. In the units stated, numerical values of (k_2) and (f) are connected by the following relationship:

$$f = \frac{5.84\ k_2 d}{1440}$$

where (d) is the mean water depth in inches.

The rate (r_t) represents the observed amount of oxygen absorbed, in grams per square meter of water surface per day, as figured from the measured gain in D.O. content from Sta. 1–5 to each point. The rate (r_o) has been obtained by dividing the observed rate (r_t) by the average oxygen saturation deficiency in each stretch of the channel. It represents the maximum or "initial" rate of absorption at zero oxygen saturation, assuming that the rate is directly proportional to the percentage of saturation deficiency. This assumption has been definitely confirmed under stream-flow conditions by results which will be referred to later in this paper. It will be noted in the table that coincidently with diminishing oxygen saturation deficiencies and increasing percentages of saturation in the water, the observed values of (r_t) tended to decline, whereas the corresponding "initial" rates (r_o) remained very nearly constant.

* THIS JOURNAL, 7, 534–552 (May, 1935).

From the results of individual observations made at various water temperatures, depths and rates of flow, a series of tabulations was made, based on average results obtained for each depth and rate of flow with mean water temperatures in the channel falling within three different ranges, varying slightly for the different series, but approximating the ranges, 0–10° C., 10–20° C., and 20–30° C. In Table II is given a tabulation of these average results, being obtained in this case from observations made with a mean flow depth of 3 inches, a flow rate of 0.75 gal. per min. through the channel, and three different ranges of water temperature. In this table, the values of (k_2), (f), (r_t) and (r_o) have been calculated as in connection with Table I.

TABLE II.—*Average Results of Observations with Mean Depth of Flow 3 Inches and Rate of Discharge 0.75 Gal. per Minute (Divided into Three Temperature Groups)*

Station	Water Temp. °C.	Avg. D.O. P.p.m.	Per Cent Sat'n	Sat'n Deficit P.p.m.	k_2 (Per day)	f (Per min.)	r_t Gms./sq.m./day	r_o Gms./sq.m./day
Temperature Range: 0–10° C.								
1–5	5.9	0.31	2.5	12.20	From Sta. 1–5			
1–90	6.4	.76	6.2	11.60	0.35	.0043	0.57	0.66
2–90	6.8	1.24	10.1	10.99	.52	.0063	.82	.88
4–90	7.1	1.84	15.2	10.30	.52	.0063	.84	.92
6–90	7.2	2.30	19.0	9.81	.48	.0058	.80	.90
8–90	7.4	2.80	23.2	9.25	.48	.0058	.78	.89
10–90	7.3	3.21	26.6	8.87	.46	.0056	.75	.88
12–90	7.6	3.56	29.7	8.43	.46	.0056	.72	.86
Temperature Range: 10–20° C.								
1–5	11.7	0.22	2.0	10.68	From Sta. 1–5			
1–90	13.6	1.00	9.6	9.46	0.83	.0101	0.98	1.04
2–90	14.3	1.25	12.1	9.05	.80	.0097	.91	.99
4–90	15.3	2.01	20.0	8.08	.85	.0104	.98	1.10
6–90	15.4	2.48	24.7	7.59	.76	.0092	.90	1.04
8–90	15.8	3.01	30.1	6.98	.75	.0091	.87	1.04
10–90	15.6	3.43	34.2	6.60	.70	.0085	.83	1.03
12–90	16.3	3.79	38.4	6.10	.69	.0084	.79	1.00
Temperature Range: 20–30° C.								
1–5	17.3	0.27	2.8	9.41	From Sta. 1–5			
1–90	20.6	1.04	11.5	8.02	1.12	.0136	0.97	1.05
2–90	22.1	1.37	15.5	7.44	1.16	.0141	.97	1.08
4–90	24.4	2.16	25.5	6.31	1.23	.0150	1.04	1.21
6–90	25.8	2.71	32.8	5.54	1.19	.0145	.97	1.18
8–90	26.6	3.20	39.4	4.93	1.14	.0139	.92	1.17
10–90	26.7	3.61	44.5	4.50	1.07	.0130	.86	1.14
12–90	27.3	3.87	48.2	4.15	1.01	.0123	.79	1.09

Temperature Range: 0–10° C.

In Table II, it is noted that in the higher ranges of temperature, a measurable increase was observed in the total amount of oxygen absorption, both in parts per million and in percentage of oxygen saturation, between the entrance point and each downstream station. This

tendency was also reflected by increased values of (k_2), (f), (r_t) and (r_o) in the higher temperature ranges.

In Table III a complete set of average results has been given for the entire length of the channel extending from Station 1–5 to Station 12–90, the data being divided primarily into three temperature groups and secondarily according to rates and depths of flow. In the last column of the table, the observed rates of reaeration (r_t) have been omitted, their equivalent initial rates (r_o) at zero oxygen saturation

TABLE III.—*Measured Rates of Reaeration, Stations 1–5 to 12–90, under Various Conditions of Temperature, Flow and Depth, with Depths = 2, 3, and 4 Inches*

Discharge Gals./Min.	Depth, Inches	Velocity, Ft./Min.	k_2 (Per day)	f (Per Min.)	r_o Gms./sq.m./day
Temperatures: 0–10° C.					
0.5	2	2.2	0.53	.0043	0.81
	3	1.4	.37	.0045	.66
	4	1.1	.26	.0042	.75
0.75	2	3.2	.71	.0058	.99
	3	2.2	.46	.0056	.88
	4	1.6	.20	.0032	.69
1.5	2	6.4	.91	.0074	1.19
	3	4.3	.54	.0066	1.07
	4	3.2	.42	.0068	1.22
Temperatures: 10–20° C.					
0.5	2	2.2	.88	.0071	.94
	3	1.4	.56	.0068	.75
	4	1.1	.34	.0055	.71
0.75	2	3.2	1.06	.0086	1.10
	3	2.2	.69	.0084	1.04
	4	1.6	.53	.0086	1.35
1.5	2	6.4	1.52	.0123	1.33
	3	4.3	.93	.0113	1.40
	4	3.2	.69	.0112	1.30
Temperatures: 20–30° C.					
0.5	2	2.2	1.15	.0093	1.27
0.75	2	3.2	1.65	.0134	1.21
	3	2.2	1.01	.0123	1.12
	4	1.6	.82	.0133	1.37
1.5	2	6.4	2.61	.0212	1.87
	3	4.3	1.32	.0161	1.47
	4	3.2	1.16	.0188	1.62

being given. Although the rates of reaeration as given in the table for each temperature and rate of flow were influenced by two variables, the velocity of current and the depth, the effect of each one of these two variables can be roughly gauged by comparing individual figures. Thus it is shown that with approximately equal velocities of flow, the surface rate of reaeration, as represented by (f) and also by the initial rate (r_o), tended to increase slightly with the depth of flow. More clearly shown is the marked increase in reaeration rate with the velocity of flow, as is indicated by comparing the rates observed at the same depths and different velocities.

In order to facilitate comparison of the rates of reaeration observed at different velocities of flow, the results given in Table III have been averaged for all three depths of flow and summarized in Table IV. As the mean depth of flow was the same for each set of results (*i.e.* 3 inches), the effect of this variable has been eliminated and the influence exerted on the observed rates of reaeration by increases in the velocity of flow are due wholly to corresponding increases in the stream discharge. In this table, as in Table III, the observed rates (r_t) have been omitted, as they were influenced by slight variations in the percentages of oxygen saturation in each temperature and flow group.

TABLE IV.—*Average Values of* (k_2), (f) *and* (r_o) *for All Depths as Observed from Station 1–5 to Station 12–90*

Temperature Range, ° C.	Discharge Gals./Min.	Velocity Ft./Min.	k_2	f	r_o
0–10	.50	1.6	0.39	.0042	0.74
	.75	2.3	.46	.0049	.85
	1.50	4.6	.62	.0069	1.16
10–20	.50	1.6	.59	.0065	.78
	.75	2.3	.76	.0085	1.07
	1.50	4.6	1.05	.0116	1.35
20–30	.50	1.6	——	——	——
	.75	2.3	1.16	.0130	1.23
	1.50	4.6	1.70	.0187	1.65

Reference to Table IV shows that values of (k_2), (f) and (r_o) increased consistently with the velocity of flow, indicating corresponding increases in the rate of reaeration. In Figure 1, the data of Table IV have been plotted on logarithmic scales, with velocities of flow as abscissae. Denoting the velocity as (V), the following relationships between (V) and (k_2), (f) and (r_o) have been derived from the plots:

Temp. ° C.	(k_2)	(f)	(r_o)
0–10	$.32V^{.43}$	$.00155V^{.42}$	$.59V^{.45}$
10–20	$.50V^{.50}$	$.0024V^{.48}$	$.70V^{.44}$
20–30	$.75V^{.51}$	$.0073V^{.50}$	$.85V^{.44}$

The exponents of the velocity (V) in these relationships varied within a comparatively narrow range (*i.e.* from 0.42 to 0.51), their approximation to a value of 0.5 indicating that the rate of reaeration,

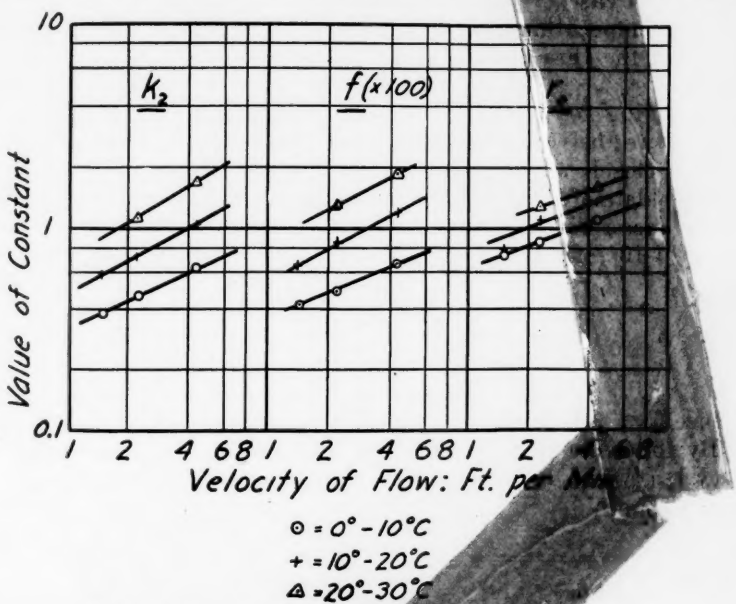

FIG. 1.—Plot of data in Table IV (logarithmic scales).

under the conditions of the experiments, tended to vary roughly as the square-root of the velocity of flow. The coefficients of (V), on the other hand, showed a marked upward trend with increase in water temperature, suggesting again a direct relationship between temperature and the rate of reaeration.

Effect of Temperature Variations.—Although the effect of increased water temperatures on the measured rates of reaeration is clearly shown by the trend of the data in Table III, it is perhaps more simply indicated by the corresponding trend of the average values of (k_2), (f) and (r_o) in Table IV, and by that of the coefficient of (V) in the relationships derived from the plots of Figure 1.

In order to obtain a numerical index of this temperature effect, use has been made of the thermal coefficient (θ) in the relationship given by equation (2) in connection with the first paper of this series, which equation is as follows:

$$\theta^{(T'-T)} = \frac{k'}{k}$$

where (k') and (k) are specific rate constants observed at two different water temperatures (T') and (T). In the equation originally cited (θ) was taken as a measure of the effect of increased temperatures on

the specific rate of biochemical oxidation and its mean value has been given, as approximating 1.047, from observations cited by Phelps and the writer and confirmed by later observations of Theriault. In the present case (θ) has been taken as a measure of the effect of increased temperatures on average values of (k_2), (f) and (r_o) as observed in the three temperature ranges, 0–10° C., 10–20° C., and 20–30° C.

Assuming for purposes of computation that the interval of mean temperature between each successive pair of these ranges was 10° C., which it closely approximated, values of (θ) may be calculated readily from the data of Table IV. If, for example, the values of (k_2) observed with a mean discharge of 0.5 gal. per minute and the temperature ranges 0–10° and 10–20° be used for such a calculation, we may write that

$$\theta^{10} = \frac{0.59}{0.39} = 1.515$$

whence $\theta = (1.515)^{1/10} = 1.042$.

By following the same method for the other corresponding values of (k_2), (f) and (r_o), the following values of (θ) have been obtained from Table IV.

Temperature Interval ° C.	Mean Discharge Gals./Min.	Value of θ, Based on		
		(k_2)	(f)	(r_o)
0–10 to 10–20	.50	1.042	1.039	1.005
	.75	1.051	1.058	1.023
	1.50	1.054	1.054	1.015
10–20 to 20–30	.50	——	——	——
	.75	1.043	1.044	1.014
	1.50	1.049	1.047	1.020
	Means	1.047	1.048	1.015

If corresponding values of (θ) be computed from the coefficients of (V) in the relationships derived from Figure 1, the following results are obtained:

Temperature Interval ° C.	Value of θ Based on Coefficient for		
	(k_2)	(f)	(r_o)
0–10 to 10–20	1.046	1.045	1.017
10–20 to 20–30	1.042	1.045	1.019
Means	1.044	1.045	1.016

The significance of these values may be explained by noting that a value of (θ) equal to 1.047, the average obtained from (k_2) ratios in the first series, means an increase of 4.7 per cent in the value of (k_2) for each degree Centigrade increase in temperature. Although the values of (θ) based on the specific constants (k_2) and (f) are shown to have agreed very closely, those derived from the rate (r_o) were distinctly lower, being unaffected by changes in oxygen saturation at different temperatures. It is of interest to note that the latter values, averaging 1.015 and 1.016 for the two series, were very nearly the same as the value, 1.0159, derived by Streeter * from data reported by Haslam, Hersey and Keen † from their extensive observations of the absorption of gases by water at different temperatures. Although this value was originally suggested as a correction factor for temperature variations in the specific rate coefficient (k_2), a later review of Haslam, Hersey and Keen's data has indicated that it is more correctly applicable to variations in the rate of reaeration per unit of surface area; hence, is directly comparable with the above values based on the rate (r_o).

It also is of interest to note that the average values of (θ) obtained for (k_2) and (f) from the present experiments, ranging from 1.044 to 1.048, were practically equivalent to the value 1.047 reported by Streeter and Phelps ‡ from their observations of temperature variations in the specific rate of biochemical oxidation of sewage and polluted water. This would indicate that the rate of atmospheric reaeration observed in these experiments was influenced by temperature variations to about the same extent as is the rate of biochemical oxidation of waters polluted by sewage; possibly a coincidence, but convenient as a matter of record.

Effect of Depth Variations.—Little if any indication was evident from the foregoing data as to any consistent influence exerted by variations in the stream depth on the rate of surface reaeration, though plots of the data in Table III, with velocities of flow as abscissae and values of (f) or (r_o) as ordinates, have shown a tendency toward slightly increased surface rates of reaeration with increased depths. It is possible that in the case at hand the differences in flow depth were too small to bring out clearly any well-marked effect of this variable, except to suggest that where the depth was increased, with a given mean velocity of flow, some hydraulic condition may have caused a slightly greater degree of turbulence than with more shallow depths.

Influence of Diffusion. In connection with the foregoing experiments, an opportunity was afforded to test the applicability of the laws of hydro-diffusion to the absorption of atmospheric oxygen by streams of water moving along a smooth channel with extremely slow current velocities and under conditions approaching closely those of stream-line flow. The theory underlying this phenomenon in quiescent

* Public Health Reports, February 12, 1926, pp. 247–262 (Reprint No. 1063); *Trans. Amer. Soc. C.E.*, 89, 1351–1364, 1926.

† *Jour. Ind. and Eng. Chemistry*, December, 1924, 1224–1230.

‡ Public Health Bulletin No. 146, U. S. Public Health Service, pp. 8–9.

and semi-quiescent bodies of water was developed originally by Black and Phelps,* and applied by them to calculations of the relative effect of atmospheric reaeration in the waters of New York harbor. From a study of Fick's law of hydro-diffusion, they developed the following equation between the initial D.O. content of a column of water, its final content after any given time and the various dimensional factors concerned:

$$D = 100 - \left[\left(1 - \frac{B}{100}\right) \cdot 81.06 \cdot \left(0.779^K + \frac{0.105^K}{9} + \frac{0.0019^K}{25} + \cdots\right)\right]$$

where B = initial D.O. in per cent saturation
D = final D.O. in per cent saturation
K = a constant for each experiment

$$= \frac{\pi^2 at}{L^2} = \frac{2.467\, at}{L^2}$$

t = time in hours
L = depth of water in centimeters
a = diffusion coefficient, varying with the water temperature.

In the present instance, the effect of variations even in extremely low velocities of flow on the rate of reaeration was apparent, though the gradient of this effect was so low as to suggest that some influence other than physical agitation was operative. From the trend of the plots in Figure 1, it is thus apparent that with velocities of flow approaching zero, or a state of complete quiescence, the rate of reaeration remained appreciable in magnitude, averaging nearly one gram per square meter per day in terms of (r_o) with an extremely low velocity of one foot per minute.

In order to test the application of the Black-Phelps formula to the present data, a number of calculations were made of the changes in dissolved oxygen saturation, between certain successive stations in the channel, resulting from diffusion, based in each case on the observed D.O. content at the next upper station, and the results were compared with those correspondingly observed. In Table V is a typical set of results of these calculations, based on four individual experiments made during a period in which the water temperature approached 20° C. In this table the successive steps in each calculation are shown by indicating the numerical values, both observed and computed, of the various terms in the Black-Phelps formula. In the two columns at the extreme right-hand edge of the table are compared the calculated percentages of D.O. saturation and those actually observed.

On reference to this table, it is noted that the calculated changes in D.O. between each successive pair of stations corresponded quite closely to the observed changes, though with two exceptions they were slightly

* Black, W. M., and Phelps, E. B., Report on Discharge of Water into New York Harbor, 1911. (Reprinted in *Contributions from the Sanitary Research Laboratory and Sewage Experiment Station*, Mass. Institute of Technology, Vol. VII, 1911.)

TABLE V.—*Calculated Changes in D.O. Saturation from Station to Station in Continuous Flow Channel by the Black-Phelps Diffusion Formula,* as Compared with Observed Results, Based on Data from Four Experiments. Discharge = 0.75 Gals. per Min. Mean Velocity of Flow = 2.3 Ft. per Min.*

Date 1932	Stations		Mean Temp. ° C.	"a"	t (hrs.)	L^2	"K" (1)	1−[B/100]	Sum. of Series (2)	Products (% Sat.) (3)	Final D.O.—% Sat.	
	From	To									Calc'd "D" (4)	Obs'd
5/10	1–5	1–90	17.5	1.2	2.0	100	0.059	0.950	1.112	85.6	14.4	12.8
	1–90	4–90	18.4	1.3	2.9	137	.068	.872	1.106	78.0	22.0	20.7
	4–90	8–90	19.0	1.4	4.2	161	.090	.793	1.093	70.0	30.0	27.8
	8–90	12–90	19.4	1.4	4.5	197	.079	.722	1.097	64.0	36.0	34.0
5/11	1–5	1–90	17.7	1.2	2.0	107	.055	.884	1.112	79.2	20.8	19.7
	1–90	4–90	18.6	1.3	2.9	137	.068	.803	1.104	71.8	28.2	28.8
	4–90	8–90	19.3	1.4	4.2	161	.090	.712	1.091	63.0	37.0	33.3
	8–90	12–90	19.6	1.4	4.4	181	.084	.667	1.095	59.3	40.7	37.4
5/12	1–5	1–90	18.5	1.3	2.0	107	.060	.815	1.109	73.2	26.8	23.5
	1–90	4–90	19.1	1.4	2.9	137	.073	.765	1.101	68.2	31.8	30.0
	4–90	8–90	19.4	1.4	4.2	161	.090	.700	1.091	61.9	38.1	34.5
	8–90	12–90	19.5	1.4	4.4	181	.084	.655	1.096	57.9	42.1	37.8
5/13	1–5	1–90	19.9	1.4	2.0	107	.062	.762	1.108	68.4	31.6	31.5
	1–90	4–90	21.0	1.6	2.9	137	.083	.685	1.095	60.8	39.2	40.6
	4–90	8–90	22.0	1.8	4.2	161	.115	.594	1.077	51.7	48.3	45.4
	8–90	12–90	22.4	1.9	4.4	181	.115	.546	1.077	47.6	52.4	49.0

(1) $K = \frac{2.467\,at}{L^2}$. (2) Sum of series $= \left(0.779^K + \frac{1.105^K}{9} + \frac{0.0019^K}{25}\right)$. (3) Product $= [(1-B/100)^9 \cdot 81.06^{25} \cdot$ Sum of Series]. (4) $D = 100 -$ Product (3).

higher than those observed. This one-sided deviation may have been due to the fact that the actual times of flow of water between the stations were less than those assumed, which were based on the mean velocity of flow, or to some other systematic error of observation. The striking general agreement between the calculated and observed results suggests, however, that under the extremely sluggish conditions of flow prevailing in the continuous-flow channel during the course of these experiments, hydro-diffusion probably exerted a primary influence on the total amount of oxygen absorbed through reaeration, with slight agitation of the water resulting from its slow movement playing a secondary part.

B. Recirculation Channel Experiments

In the continuous-flow channel experiments, described in the foregoing part of this paper, the observations were necessarily restricted to low velocities of flow, ranging below 10 ft. per minute. As velocities of this low order of magnitude would constitute an extremely sluggish

current in a natural stream, it was desired to carry out some further measurements at high velocities, ranging up to 40 or 50 ft. per min. or more, in order to approach more closely the conditions found in freely-flowing streams.

For this purpose it was possible to utilize the recirculation principle in a channel of relatively short length, by arranging the channel in the form of a continuous loop, as previously described. Both the larger and smaller channels of this type were arranged in six parallel sections or bays, connected in series with each other, with a cross-connecting section at one end of the tank joining the ends of the first and sixth bays and thus completing the loop. In the following table are shown the comparative main dimensions of the two channels:

	Small Channel	Large Channel
Length of containing tank	27 in.	120 in.
Width of tank	18 in.	36 in.
Cross-sectional width of bay	3 in.	6 in.
Cross-sectional depth of bay	6 in.	18 in.
Cross-sectional area of bay	18 sq. in.	108 sq. in.
Total volume at full depth	60.6 liters	1240 liters
Total surface area	0.398 sq. meter	2.71 sq. meters
Total length of flow for one circulation	17.2 ft.	58.4 ft.

In the second bay of each channel is a horizontal shaft, running lengthwise, equipped with inclined propeller blades which rotate with the shaft. Power is transmitted from a small motor through a speed-reducing gear and step-pulleys. Variations in the speed of rotation of the propeller shaft are obtained through different combinations of pulleys, the motor being of constant speed. Velocities of flow of water in the larger channel may be varied from 2 to 73 ft. per min. by varying the depth of water from 15 to 9 in. and the speed of the propeller rotation from 40 to 800 r.p.m., the velocity of flow being nearly proportional to the propeller speed with a given depth of water.

The method of operating the recirculation channels differed in one respect from that of operating the continuous-flow channel, in that the same body of water remained in them throughout a given experiment. In order to observe the rate of absorption of atmospheric oxygen by water flowing in one of the recirculation channels, it was necessary to measure the rate of increase in the dissolved oxygen content of a fixed volume of water, partially or wholly deaerated initially. With the smaller channel, it was a comparatively simple matter to pre-deaerate the relatively small volume of water required, by passing it through a column of iron filings in filling the channel tank to a given depth, as the period of filling it was sufficiently short to allow only a small degree of reaeration during this operation.

In the larger channel, however, the time required for adding to the tank the much larger volume of water needed was so long that reaeration had advanced to a very considerable degree when the filling opera-

tion had been completed; hence, it was necessary to seek another method, permitting deaeration of the water after it had been added to the tank. The method which gave the best results involved the use of sodium sulphite as a deaerating medium, followed by the addition of just enough chlorine to the deaerated water to neutralize the excess of sulphite not absorbed in the deaerating reaction. By careful regulation of the amounts of sulphite and chlorine added, it was found possible to deaerate the entire contents of the channel within a few minutes of time and then proceed with the reaeration measurement, starting with a water containing usually less than 1.0 p.p.m. of dissolved oxygen. The reactions involved were very simple, being as follows:

$$(1)\ Na_2SO_3 + O \text{ (from the water)} \rightarrow Na_2SO_4$$
$$(2)\ Na_2SO_3 \text{ (excess)} + Cl_2 + H_2O \rightarrow Na_2SO_4 + 2HCl.$$

In making the subsequent dissolved oxygen tests, it was necessary to deal with a slight excess of chlorine present in the water, but as the excess was usually very small, this correction was not difficult and entailed no appreciable error.

An alternative method of measuring rates of atmospheric reaeration in the recirculation channels was suggested by the work of Miyamoto * and his associates in Japan, who used solutions of sodium sulphite to measure the "initial," or maximum, rates of absorption of atmospheric oxygen at zero oxygen saturation in the absorbing solution. The theory underlying this method of measurement is that as oxygen is absorbed at the surface of a sulphite solution, it is rapidly reabsorbed by the sulphite in accordance with the simple reaction (1) above stated. Hence the surface absorption always proceeds at the maximum zero saturation rate consistent with the temperature, the oxygen gas pressure at the surface and the degree of agitation of the absorbing solution. This general method of procedure was tried in the present series of experiments, with results which will be described at a later point in this paper.

Measurements With Pre-deaerated Water.—For the first series of series of experiments, the smaller recirculation channel was used, tap water being pre-deaerated by passing it through a column of iron filings and thence into the channel to a depth approximating 4 inches. A different velocity of flow was obtained for each experiment by varying the propeller speed. In other experiments the depth was varied from 3 to 5 in. and the water temperature from 10° to 20° C.

In order to illustrate a typical set of results from the individual experiments, Table VI has been prepared, showing the results of a 3.5-hr. test with a mean water depth of 3.8 in. and a velocity of flow 23.8 ft. per minute. In the first section of the table are recorded the observed water temperatures and dissolved oxygen contents, determined a 15-min. intervals up to the 3-hr. reading. The latter have been converted to percentages of saturation and saturation deficiencies, based

* *Bulletins of the Chemical Society of Japan*, Vol. 2 (1927), 74–78; Vol. 3, No. 4 (1928), 98–101; Vol. 5, No. 8 (1930), 229–240; Vol. 5, No. 11 (1930), 321–325.

on standard saturation values for distilled water at the recorded temperatures. In the second section of the table, the observed increases in dissolved oxygen during each successive interval have been converted to rates per hour, in milligrams per liter (p.p.m.) and the corresponding mean percentages of oxygen saturation have been computed from those observed at the beginning and end of each interval.

TABLE VI.—*Results of Typical Measurement of Atmospheric Reaeration in Small Recirculation Channel, with Stream Depth 3.8 Inches and Velocity of Flow 23.8 Feet per Minute (Tap Water Pre-deaerated by Iron Filings)*

Time from Start (Hrs.)	Temp. (° C.)	Observed D.O. P.p.m.	% Sat'n	Sat'n %	Deficit P.p.m.	D.O. Increase (P.p.m.)		Avg. % Sat'n
						Obs'd	Rate per Hr.	
0.00	13.	1.41	13.3	86.7	9.19			
						2.34	9.36	29.4
.25	13.	3.75	35.4	64.6	6.85			
						1.48	5.92	42.4
.50	13.	5.23	49.3	50.7	5.37			
						1.37	5.48	55.8
.75	13.	6.60	62.2	37.8	4.00			
						.91	3.64	67.0
1.00	13.5	7.51	71.9	28.1	2.97			
						.71	2.84	75.2
1.25	13.5	8.22	78.6	21.4	2.26			
						.46	1.84	81.2
1.50	14.	8.68	83.7	16.3	1.69			
						.41	1.64	85.7
1.75	14.	9.09	87.7	12.3	1.28			
						.25	1.00	88.9
2.00	14.	9.34	90.1	9.9	1.03			
						.25	1.00	91.3
2.25	14.	9.59	92.5	7.5	.78			
						.11	.44	93.6
2.50	14.	9.70	94.6	5.4	.56			
						.05	.20	94.8
2.75	14.5	9.75	95.1	4.9	.51			
						.08	.32	95.5
3.00	14.5	9.83	95.9	4.1	.43			
						.05	.10	96.6
3.50	15.	9.88	97.3	2.7	.27			

A plot of these oxygen absorption rates against the mean percentages of oxygen saturation is shown in Figure 2. Although the positions of these points were influenced to some extent by errors of observation and by the assumption of a constant average oxygen saturation during each successive time interval between samplings, their close approximation to a straight-line trend is clearly shown, thus indicating that the rate of absorption of atmospheric oxygen tended to vary inversely with the degree of oxygen saturation and directly with the

saturation deficiency. This observation was confirmed by the results of every test made during the experiments.

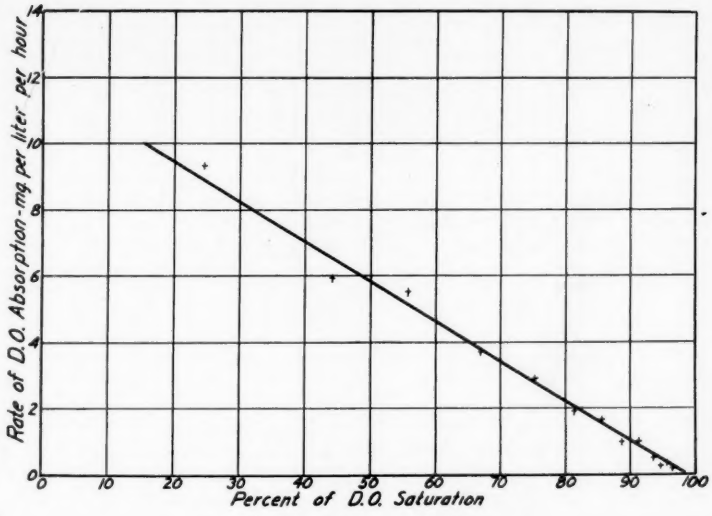

FIG. 2.—Plot of data in Table VI.

A more exact way of showing this relationship is illustrated by Figure 3, in which semi-logarithmic plots have been made of the data from five separate experiments of the same series, including the one dealt with in Table VI and Figure 2. In this chart, the time scale is linear, as in Figure 2, but the ordinate scale is logarithmic and on it are plotted the oxygen saturation deficiencies observed initially and after each successive interval of time. It will be noted that the plotted trend of these deficiencies was downward from the origin along straight lines having different slopes, each slope being a measure of the rate of decrease in saturation deficiency and hence the rate of reaeration. As the slope of a particular line is measured by the constant (k_2), the initial saturation deficiency at zero time by (D_a) and the remaining deficiency at any time (t) by (D_t), the equation of the line may be written as:

$$\log D_t = \log D_a - k_2 t$$

whence

$$\log D_t - \log D_a = \log \frac{D_t}{D_a} = -k_2 t. \qquad (1)$$

When expressed in terms of natural logarithms this equation becomes:

$$\ln \frac{D_t}{D_a} = -2.3\, k_2 t. \qquad (2)$$

Differentiating expression (2), we have

$$\frac{dD_t}{D_t} = -2.3\, k_2 dt$$

whence

$$-\frac{dD_t}{dt} = 2.3\, k_2 D_t. \qquad (3)$$

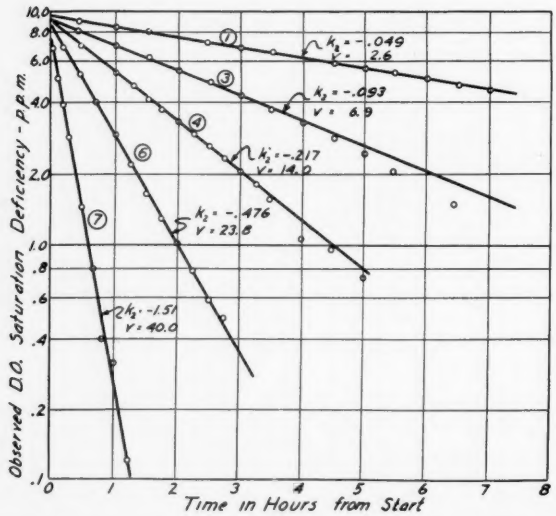

FIG. 3.—Semi-logarithmic plot of data from five experiments, showing linear relation between time and logarithms of observed oxygen saturation deficiency, and illustrating variations in specific rate of reaeration (k_2) with different velocities of flow.

As the differential coefficient (dD_t/dt) is a measure of the momentary rate of oxygen absorption at any time (t), equation (3) shows that this rate is directly proportional to the oxygen saturation deficiency (D_t), whenever the course of oxygen absorption follows a true logarithmic time-function curve such as illustrated in Figure 3. The negative sign of this rate in the equation is due to the fact that in an oxygen absorption of the kind portrayed, the oxygen saturation deficiency (D_t) and hence the rate of absorption is a diminishing function of time.

The effect of applying equation (3) to the experimental data of Table VI is shown in Figure 4, in which numerical values of (dD_t/dt) designated by the symbol (r_t), have been calculated for each successive observation in the experiment and plotted against corresponding observed oxygen saturation deficiencies. In this case the plotted rates fall almost exactly along a straight line, which also follows closely the trend of the points transcribed from Figure 3 (indicated by the crosses).

The chief interest of these preliminary experiments, aside from establishing a working technique for further observations, was in the

consistent evidence afforded by them as to the direct proportionality existing between the rate of absorption of atmospheric oxygen by a moving body of water and the degree of oxygen saturation deficiency

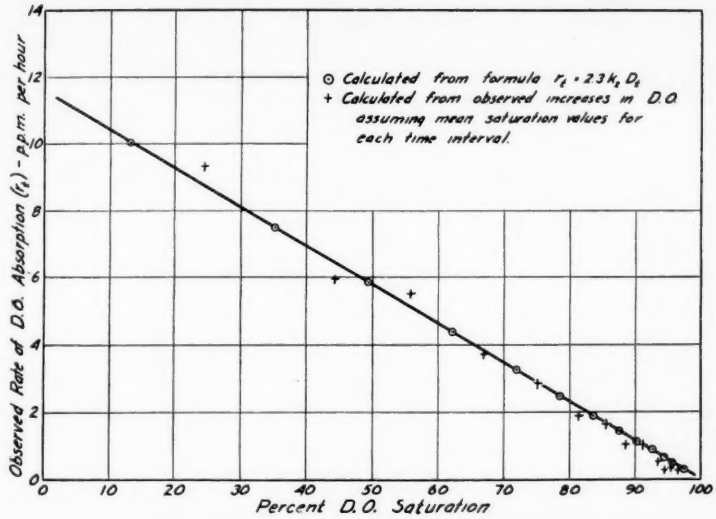

FIG. 4.—Plot of reaeration rates (r_t) as calculated from equation (3) and from observed increases in dissolved oxygen content.

prevailing in the water at a given time. Although this proportionality has in general been assumed as being in accordance with the laws governing similar liquid-gas absorption phenomena, experimental evidence bearing directly on its applicability to flowing streams of water has been somewhat lacking. Its demonstration in the present instance over a wide range of saturation values and flow velocities, the latter varying from those of extremely sluggish to fairly rapid flow, was further confirmed by the results of later experiments in the larger channel.

From values of the reaeration coefficient (k_2) determined as illustrated in Figure 3, it was possible to calculate by means of equation (3) for each one of the seven experiments previously described, the maximum rate of atmospheric reaeration at an assumed zero degree of oxygen saturation, for comparison with the other rates observed at different velocities of flow. In Table VII are given the data on which this calculation was based, together with the resulting initial rates, designated as (r_o), expressed in parts per million per hour and grams of oxygen per square meter of water surface per day. In calculating (r_o) for an assumed zero oxygen saturation, the total oxygen saturation value (D_o) at the observed mean water temperature was taken as the value of (D_t) for substitution in the formula. For experiment (1), the resulting rate was calculated thus:

$$r_o = 2.3 \times .049 \times 10.83 = 1.22 \text{ p.p.m, per hour,}$$

the remaining rates being similarly obtained.

An inspection of Table VII shows the direct relationship observed between the maximum rates thus calculated and the mean velocities of flow. As the average temperature for the several experiments varied over a comparatively small range, this factor probably exerted little influence on the relationship observed.

TABLE VII.—*Results of Seven Reaeration Measurements in Small Recirculation Channel, Using Tap Water Pre-deaerated by Iron Filings*

Expt. No.	Avg. Temp. ° C.	Velocity Ft./Min.	k_2 (Per hour)	D_o P.p.m.	r_o	
					P.p.m./hr.	Gms./sq. m./day
1	12.0	2.6	.049	10.83	1.22	3.0
2	14.3	3.3	.060	10.30	1.42	3.5
3	14.7	6.9	.093	10.22	2.19	5.3
4*	15.7	14.	.217	10.01	5.00	12.2
5*	18.7	14.	.245	9.41	5.30	12.9
6	14.0	23.8	.476	10.37	11.34	27.6
7	12.8	40.	1.51	10.65	36.9	90.

* Check runs.

In the corresponding series of measurements with deaerated water in the larger recirculation channel, it was found impracticable to use the iron filings column as a deaerator, for the reason previously noted. The method followed, which consisted in deoxygenating the water initially with sodium sulphite and then absorbing the excess of sulphite with chlorine, gave very good results after a few trial runs. From a series of 11 experiments, all made at temperatures around 20° C., the results given in Table VIII were obtained. In this case two check measurements were made at a flow velocity of 6 ft. per min. and three each at velocities around 9 and 25 ft. per minute, respectively, the results of these tests being given both separately and as averages in the table. As the entire series of experiments was made with a water depth of 12 in. in the channel, the comparative results obtained were little influenced by differences either in temperature or in depth.

The results of this series of tests in the larger channel and of the previous series in the smaller channel, have been compared graphically in Figure 5, in which the respective observed rates of reaeration, in gm. per sq. in. of water surface per day, have been plotted against corresponding velocities of flow, in ft. per minute. For velocities up to 25 ft. per min. the two plots are very nearly coincident with each other, indicating that within the lower velocity ranges the observed rates of reaeration were practically the same in the two channels, despite the greater depths of flow in the larger channel (*i.e.* about three times greater than in the smaller channel). For velocities above 25 ft. per min. the two plots diverge sharply, with the sharp upward trend of the plot based on the smaller channel results. This divergence appears to have been due mainly to the fact that in the smaller channel the propeller was less submerged and at higher speeds caused a noticeably

TABLE VIII.—*Results of Eleven Reaeration Measurements in Large Recirculation Channel, Using Tap Water Pre-deaerated by Sodium Sulphite*

Velocity Ft./Min.		Temp. ° C.	k_2 (Per hour)	r_o (Gms./sq.m./day)	
Obs'd	Mean			Obs'd	Mean
6.0*		21	.0294	4.4	
6.0*	6.0	21	.0257	3.9	4.2
9.3*		23	.0578	8.4	
9.3*		23	.0589	8.5	
9.4*	9.3	26	.0535	7.4	8.1
18.		26	.147	20.0	
24.0*		20.1	.176	26.8	
24.0*		19.5	.200	30.8	
25.5*	24.5	20.5	.170	25.8	27.8
34.		20.	.263	40.3	
47.		25.	.390	54.0	

* Check runs.

greater degree of surface agitation, with correspondingly greater increase in the surface of water exposed to reaeration. In the larger channel, with the propeller well submerged (in this case it was adjustable vertically to three different positions), the surface agitation and surface area were not so greatly affected by higher propeller speeds; hence the rate of reaeration increased much more nearly in proportion to the velocity of flow.

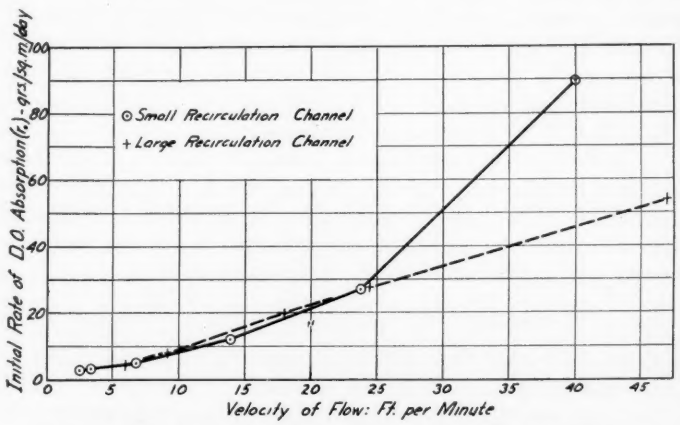

FIG. 5.—Comparative plots of data in Tables VII and VIII.

Measurements With Sodium Sulphite Solutions.—From the earlier papers of Miyamoto and his co-workers * it appeared that the rate of

* *Loc. cit.*

absorption of atmospheric oxygen by solutions of sodium sulphite should be little affected by variations in the concentration of sulphite over a limited observational range, though these observers noted that the rate became diminished in very weak solutions and also in very strong solutions. For the first series of experiments, which were carried out in the small recirculation channel, it was decided to use solutions ranging in concentration from 200 to 600 p.p.m., which was decidedly weaker than the solutions utilized by Miyamoto. For the second series, made in the larger channel, the sulphite concentration was increased to an average ranging from 800 to 1200 p.p.m., in order to ascertain what, if any, effect an increase of this degree would have on the observed rates of oxygen absorption at various depths, temperatures and velocities of flow, in comparison with those observed under comparable conditions with pre-deaerated water and with lower concentrations of sulphite.

The method of procedure followed in each experiment was practically the same in both channels. After filling the channel with tap water to the pre-determined depth and adjusting it to the desired temperature (by adding hot water if necessary), a solution containing the required amount of sodium sulphite was added to the channel contents, after setting the propeller-agitator in rapid motion to expedite mixing. As soon as mixing was complete, the speed of the propeller was adjusted to that which would give the desired velocity of flow for the experiment and the first observation was then made of the temperature and sulphite content of the solution. These observations were repeated at intervals of 15 or 30 minutes throughout the period of the experiment, which varied from about 4 to 8 hours, according to the velocity of flow and consequent rate of oxygen absorption.

The method followed in measuring the oxygen absorption rate was as follows: At each pre-determined interval a 50 c.c. sample of the sulphite solution was collected from the channel at mid-depth with a volumetric pipette and placed in an Erlenmeyer flask, to which had been previously added a measured amount of N/40 iodine solution, acidified with 3 N hydrochloric acid, and always in excess of that required to neutralize the sulphite solution. After mixing the sulphite and acidified iodine solutions in the flask, the excess of iodine was titrated with N/40 sodium thiosulphate. The amount of sulphite present in the solution was then figured in terms of the equivalent amount of standard iodine absorbed by it, the reaction being:

$$Na_2SO_3 + I_2 + H_2O \rightarrow Na_2SO_4 + 2HI.$$

The decrease in sulphite concentration observed during a given interval between samplings was then calculated into terms of the oxygen required to convert the sulphite to sulphate, and this latter figure was then carried over to terms of total grams of oxygen absorbed by the total volume of solution in the channel. In the larger channel, the volume relationships were such that 1 c.c. of N/40 iodine absorbed by 50 c.c. of the sulphite solution was equivalent to 3.36 gm. of oxygen

absorbed by the total volume of solution in the channel at a depth of 12 inches. A rate of oxygen absorption equivalent to 1 c.c. of N/40 iodine per hr. would thus represent 3.36 gm. of oxygen per hr. absorbed by the entire channel contents. As the surface area of the channel was 2.72 sq. m., this rate would be equivalent to $\frac{3.36 \times 24}{2.72} = 29.6$ gm. of oxygen per sq. m. per day. By measuring the rate of decrease per hour in the number of c.c.'s of N/40 iodine solution absorbed by 50 c.c. of the sulphite solution in the channel, this figure was then readily converted to terms of oxygen absorbed, in gm. per sq. m. of surface per day, by applying the multiplying factor 29.6. With solution depths other than 12 in., this factor would vary in direct proportion to the actual depth, as the sides of the channel were vertical and the horizontal cross-section uniform for all depths with the propeller completely submerged.

Only two corrections were necessary in making these calculations. One was for any observed change in the concentration of the standard iodine solution during the period of a test, this being checked three times during each run. The other was for any corresponding change in the concentration of the standard thiosulphate solution, which was checked frequently against a standard solution of sodium biniodate, this latter solution being very stable and remaining constant in strength for long periods of time. Although each channel was calibrated initially for the relationship between propeller speed and velocity of flow, the latter was checked frequently during each test by float measurements, using a stop-watch. The temperature of the sulphite solution also was observed at each sampling time.

TABLE IX.—*Results of Typical Measurement of Absorption of Atmospheric Oxygen by Sodium Sulphite Solution in Large Recirculation Channel. Depth = 12 Inches. Velocity = 25.5 Ft./Minute*

Time from Start (Hours)	Temp. ° C.	Propeller Speed R.p.m.	Cc. N/40 Excess Iodine	Equivalent Sulphite Conc'n (c.c. N/40 I_2)	
				Obs'd	Corr'd
0.0	20.	330	0.71	40.37	40.37
.5	20.	330	1.37	39.71	39.70
1.0	19.8		1.85	39.23	39.21
1.5	19.8	329	2.43	38.65	38.62
2.0	19.8		3.02	38.06	38.02
2.5	20.		3.51	37.57	37.52
3.0	20.	330	4.12	36.96	36.90
3.5	20.		4.79	36.29	36.22
4.0	20.		5.40	35.68	35.60
4.5	20.	330	5.98	35.10	35.01
5.0	20.		6.50	34.58	34.48
5.5	20.2		7.17	33.91	33.80
6.0	20.2	328	7.78	33.30	33.18

In Table IX are given the results of a typical measurement by this method in the large recirculation channel. In Column 4 are shown the amounts of excess iodine and in Columns 5 and 6 the corresponding concentrations of sulphite, observed and corrected, all being expressed in terms of 1/40 normality. In Figure 6 is shown a plot of the corrected figures, with times from the start as abscissae. The trend of the plot follows very closely a straight line, the slope indicating the rate of oxidation of the sulphite solution. From this slope, as determined by a least-squares fitting of the line, the rate of decrease in the strength of sulphite solution was given as 1.193 c.c. per hr. (of N/40 solution) and the corresponding surface rate of oxygen absorption, $1.193 \times 29.6 = 35.3$ gm./sq. m./day.

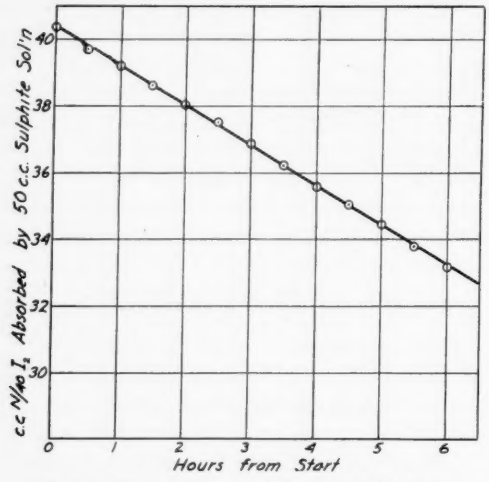

FIG. 6.—Plot of corrected data in Table IX.

Following the sulphite method above described, 17 measurements were made in the smaller recirculation channel, with average solution temperatures ranging from 14° to 23° C. and the velocity of flow from 2.6 to 40 ft. per min., six separate velocities being used within this range. In Table X are shown the results of these measurements, the observed rates of reaeration being given both individually and as averages for each different velocity. For comparison with these average rates, the "initial" rates (r_o) observed at corresponding velocities of flow in a previous series (Table VII) made with pre-deaerated water are tabulated in the last column of the table.

In Table X and Figure 7, in which comparative plots of the data given in Columns 5 and 6 of the table are given, the rates of oxygen absorption observed in the sulphite solution are shown to have been consistently higher than the corresponding initial rates in pre-deaerated water, though the deviation was relatively small except at velocities less than 10 ft. per minute.

TABLE X.—*Comparative Results of Experiments in Small Recirculation Channel Using Sodium Sulphite Solution, and Corresponding Results in Same Channel Using Pre-deaerated Water (Table VII)*

Velocity Ft./Min.	Avg. Temp. ° C.	Avg. Conc'n Na_2SO_3 P.p.m.	D.O. Absorbed—Gms./sq.m./day		
			Obs'd	Mean	(r_o) from Table VII
2.6	15.5	373	5.7		
2.6	17.5	437	5.3	5.5	3.0
3.3	14.0	340	6.7		
3.3	15.3	344	7.2	6.9	3.5
7.	15.2	320	6.3		
7.	16.0	356	7.0		
7.	19.1	524	8.9	7.4	5.3
14.	20.0	198	12.4		
14.	20.0	392	14.4		
14.	20.8	406	14.8		
14.	21.6	329	13.2		
14.	23.1	298	13.6	13.7	12.2
24.	17.0	301	29.8		
24.	22.2	380	32.2	31.0	27.6
40.	18.2	356	107.		
40.	20.2	238	85.9		
40.	22.0	677	78.3	90.4	90.0

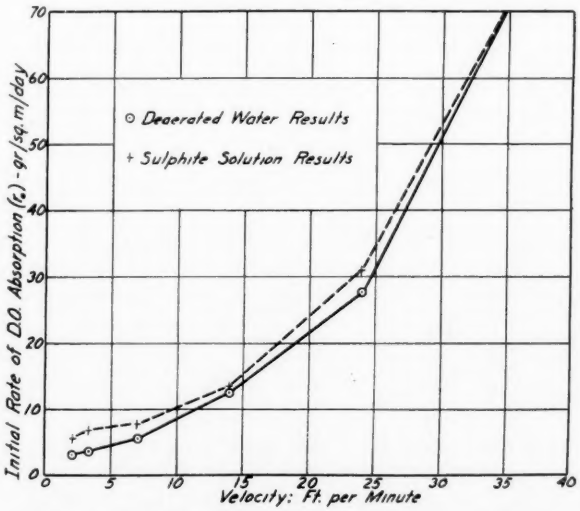

FIG. 7.—Comparative plot of data in Table X.

In Figure 8 is a re-plot of the same data, using logarithmic instead of linear scales. In this chart the plotted points are shown to follow two distinct straight-line trends, the slope breaking sharply upward at a velocity of flow approximating 10 ft. per minute. If the slope of each line based on the deaerated water tests be designated by (n) in the function (V^n), where (V) is the velocity of the flow, the numerical value of (n) for the steeper line approximates 1.75 and for the flatter line, 0.50.

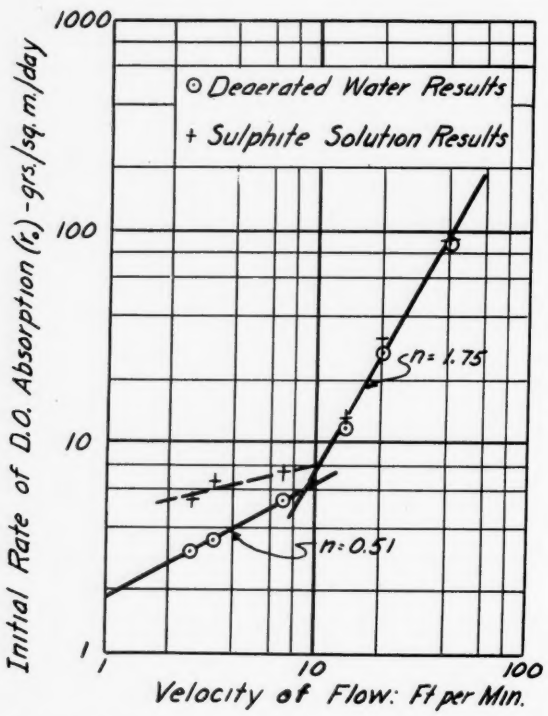

FIG. 8.—Re-plot of data in Table X, with logarithmic scales.

An interesting and possibly significant hydraulic analogy to the trend of the plots in Figure 8 has been afforded by some very recent observations by Rouse * on the mechanics of fluid turbulence in pipes. For conditions of laminar as distinguished from turbulent flow, he found that the intensity of fluid shear at the pipe wall was directly proportional to the velocity of flow, but that above a certain critical velocity at which conditions of turbulent flow become established, the shear increased with the 1.75 to 2.00 power of the velocity according to the roughness of the pipe surface. Except for the slope of the line below this critical velocity, which is steeper than in Figure 8, his plot

* Rouse, Hunter. "Modern Conceptions of the Mechanics of Fluid Turbulence." *Proc. Amer. Soc. C. E.*, **62**, 1, 21–63 (January, 1936).

of these two functions on logarithmic scales (his Fig. 3) was practically identical with that of Figure 8.

This hydraulic analogy suggests that in the experiments pictured in Figure 8, the rate of reaeration was not definitely affected by turbulent conditions of flow until the velocity exceeded about 10 ft. per min. and that below this velocity the rate was governed more largely by diffusion, such as would prevail in semiquiescent bodies of water under conditions of stream-line or laminar flow. So far as reaeration is concerned, this critical velocity probably would vary, however, for different stream channels and particularly for those in which the degrees of roughness were diverse.

In view of the indefinite character of hydraulic "turbulence" and of the difficulties involved in its direct measurement, it might be suggested from the above considerations that a fairly accurate means of evaluating turbulence may be found, in so far as open channels are concerned, in utilizing observations of rates of reaeration under varying flow and channel conditions. With proper correction for differences in stream temperature and depth, these measured rates, when observed at velocities of flow above a certain critical minimum, should afford a fairly sensitive index of turbulence of flow.

A second series of measurements with sulphite solutions was carried out in the large recirculation channel. As this channel was constructed wholly of copper, it was expected that this metal would not be readily oxidizable with ordinary tap water, after a coating of copper oxide and carbonate had formed on the contact surface. With sulphite solutions, however, it soon became apparent that the copper was being attacked and was passing into solution, where it exerted a marked catalytic effect on the oxidation of the sulphate by oxygen absorbed from the atmosphere. For this reason it was necessary to line the channel with a coating of paraffin, in order to insulate the copper from such corrosive action. This lining was very effective in preventing any further solution of the copper and the results obtained thenceforth were satisfactory.

In this series of experiments, the concentration of sulphite was higher than in the preceding series, ranging from about 800 to 1200 p.p.m., and averaging about 1000 p.p.m. This concentration, though high as compared with that used in the smaller channel series, represented a relatively weak solution, averaging only 0.1 per cent of sodium sulphite. Sixty individual "runs" were made in the series, of which 15 were for the purpose of checking previous runs. The results of these check tests were averaged, so that 45 results altogether were obtained for the series, with varying temperatures, depths and velocities of flow.

The measurements were made with stream depths of 9, 12 and 15 inches, respectively, and at each depth with velocities of flow ranging up to 73 ft. per min. and at temperatures ranging below and above 15° C. The propeller being adjustable to three different levels in the chan-

nel, it was set for each experiment at approximately mid-depth, excepting in one series of tests at 9 in. depth, when through an oversight it was placed in the next position above mid-depth. The result in this single instance was that the observed rates of reaeration were unduly affected by surface agitation from the propeller and were decidedly out of line with the other results.

In Table XI these results have been separated primarily according to temperatures below and above 15° C., and secondarily according to depths of flow. For each temperature range and depth, the results have been tabulated in ascending order of magnitude of velocities of flow.

TABLE XI.—*Results of Experiments in Large Recirculation Channel, Using Sodium Sulphite Solutions (Tabulated According to Temperatures, Depths and Flow Velocities)*

Depth = 9 inches			Depth = 12 inches			Depth = 15 inches		
Temp. ° C.	Velocity Ft./Min.	D.O. Abs'd Gms./ sq.m./ day	Temp. ° C.	Velocity Ft./Min.	D.O. Abs'd Gms./ sq.m./ day	Temp. ° C.	Velocity Ft./Min.	D.O. Abs'd Gms./ sq.m./ day
A. Temperatures Less than 15° C.								
13.5	3.3	13.4	14.5	3.0	9.3	13.0	5.5	9.1
12.9	7.0	20.2	11.3	12.0	12.8	8.3	11.3	18.3
10.9	11.2	14.4	9.3	17.0	19.0	8.8	14.2	22.2
9.8	14.4	16.6	9.5	25.5	32.7	8.4	22.2	32.6
10.0	18.2	21.8	9.7	37.2	51.7	8.6	28.7	40.0
8.8	29.1	34.1	7.5	63.7	170.	9.1	34.0	42.8
8.4	39.0	44.4				7.2	51.0	128.
7.0	72.6	308.						
B. Temperatures Greater than 15° C.								
22.0	3.3	17.2	17.4	5.0	14.4	19.	2.4	11.2
20.3	7.0	25.6	19.0	11.9	16.4	19.1	6.2	17.0
20.5	10.1	27.7	20.2	15.4	20.4	19.6	10.6	21.6
20.2	12.6	30.4	20.0	25.5	35.3	19.8	22.2	37.6
19.5	14.4	32.4	19.7	34.0	45.7	20.2	28.2	41.8
19.5	18.0	34.2	20.3	39.2	52.0	20.6	34.0	49.7
20.7	26.8	40.4	19.9	63.7	206.	18.8	40.9	77.7
20.0	36.4	43.8				20.7	46.5	92.
20.0	73.	337.						

In Figure 9 are shown plots of the data given in Table XI, for each depth of flow, allowing a comparison of the trend of rates observed at the higher and lower temperatures. The effect of surface agitation resulting from the high position of the propeller in the 9 in. depth series at the higher temperature is clearly reflected by the wide deviation of plot (*a*) from its low temperature counterpart. In Figure 10

the same plots, omitting (*a*) in Figure 9, have been re-drawn for velocities up to 40 ft., so as to show the relation between the depths of flow and the observed rates of reaeration within this range.

From a study of these charts, it appears that the surface rate of

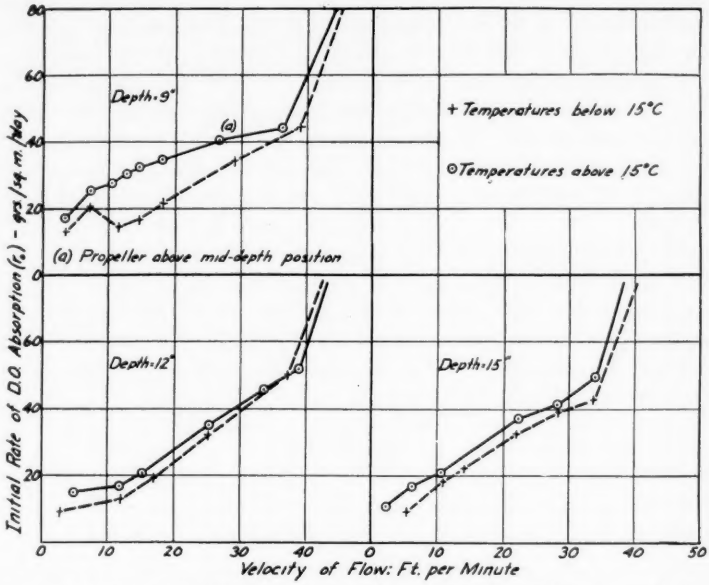

FIG. 9.—Plot of data in Table XI, comparing surface rates of reaeration observed at temperatures above and below 15° C.

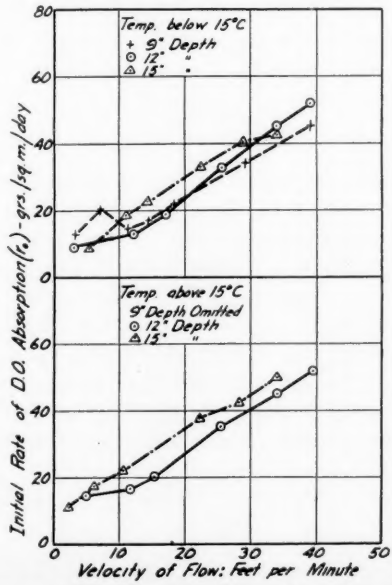

FIG. 10.—Re-plot of data in Table XI, comparing surface rates of reaeration observed at various depths.

absorption of atmospheric oxygen by the sulphite solutions was increased at higher temperatures and slightly at greater depths, but was most influenced by increases in turbulence resulting from higher velocities of flow. With velocities ranging between 10 and 40 ft. per min., the increase in absorption rate was very nearly in direct proportion to the increase in velocity as indicated by the straight-line trend of the plots in this range. With velocities higher than 40 ft. per min., the effect of increased surface area resulting from high propeller speeds is shown by the sharp upturn in the observed rates of absorption at these higher velocities. With velocities below 10 ft. per min., the absorption rate was apparently less affected by changes in velocity of flow, though this difference was only very slightly perceptible at the 15 in. depth.

When the data in Table XI were averaged for the range of flow velocities over which the observed rate of reaeration was very nearly proportional to the velocity (*i.e.* from 10 to 40 ft. per min.) an index was obtained of the average effects of temperature and depth of flow on the rate of reaeration. The results obtained from this averaging process were as in Table XII below.

TABLE XII

Depth In.	Temp. (° C.)	Velocity (Ft./min.)	D.O. Absorbed (Gm./sq.m./day)
9	9.6	22.4	26.3
	20.1	19.9	33.6*
12	10.0	22.9	29.0
	19.8	25.2	34.0
15	8.6	22.3	31.2
	20.0	23.8	37.7

* Influenced by high position of propeller.

Effect of Temperature.—The effect of temperature variations on the measured rate of reaeration may be gauged best by comparing the average rates observed at the higher and lower temperatures for depths of 12 and 15 inches. Such a comparison at the 9 in. depth would be inconclusive from this standpoint because of the disproportionately high rate of oxygen absorption (33.6 gm./sq.m./day) at the higher temperatures resulting from the unduly elevated position of the propeller. When values of the thermal coefficient (θ) were calculated at these two depths by the same formula as previously applied to the results obtained in the continuous-flow channel, the results were as follows:

$$12 \text{ in. Depth: } \theta^{(19.8-10.0)} = \frac{34.0}{29.0} = 1.172; \quad \theta = 1.172^{1/9.8} = 1.0163$$

$$15 \text{ in Depth: } \theta^{(20.0-8.6)} = \frac{37.7}{31.2} = 1.208; \quad \theta = 1.208^{1/11.4} = 1.0167$$

$$\text{Mean} = 1.0165$$

The close agreement between these two values and that obtained previously from the observations made on deaerated water in the continuous-flow channel suggests that a rounded value of (θ) approximating 1.016 fairly represents in a single figure the effect of temperature variations on the rate of stream-flow reaeration, when expressed in terms of the amount of oxygen absorbed per unit of surface area or volume at a given constant degree of oxygen saturation.

Effect of Depth of Flow.—Aside from the observations made in the continuous-flow channel, the only experiments yielding any data bearing on the effect of variations in the depth of flow on rates of reaeration were those carried out with sulphite solutions in the large recirculation channel. From the previous tests in the continuous-flow channel, it was noted (Table III) that when the effect of flow velocity was eliminated, a tendency was shown toward a slight increase in the surface rate of reaeration with increasing water depth, though this tendency was not consistently displayed and the range of depths over which it was observable was extremely limited.

On referring to Figure 10, a similar tendency is noted except in the trend of reaeration rates observed at 12 in. depth and at the lower temperatures. In this case no comparison was practicable with 9 in. depth in the higher temperature range, as the results of this series were unduly influenced by the high position of the propeller. By substituting for the average rate observed in this series (*i.e.* 33.6 gm./sq.m./day) a figure based on the corresponding low temperature rate and corrected from a mean temperature of 9.6° C. to one of 20.1° C., it has been possible to make a fair comparison of the average rates observed with depths of 9, 12 and 15 inches, both in the high and in the low temperature series.

From these average data, as computed from Table XI, and tabulated in the immediately foregoing text, a logarithmic plot has been made,

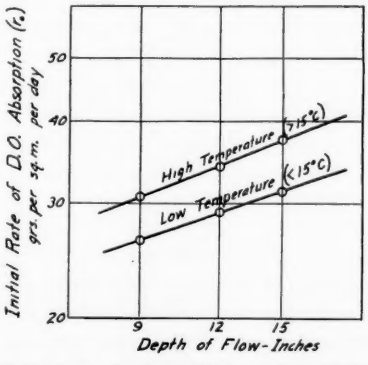

FIG. 11.—Plot of data in Table XII, showing relations observed between depths of flow and surface rates of reaeration (Logarithmic scales).

in Figure 11, of the relationship shown between the observed average rates of reaeration and the three different depths, 9, 12 and 15 inches,

at which these rates were observed. In this plot the corrected rate at 9 in. depth (31. gm./sq.m./day) has been substituted for the excessive observed rate. With this exception, the rates plotted are those given in Table XII.

In Figure 11, an orderly increase in the observed mean rate of reaeration is shown with increasing depths of flow, though the extent of increase was not large, being roughly in proportion to the cube-root of the depth. According to this relationship, an eight-fold increase in the depth of flow would be required in order to produce a two-fold increase in the surface rate of reaeration.

Although this observation was at variance with the consistency shown between the rates of reaeration measured in the larger and smaller recirculation channels, with depths of flow three times greater in the larger than in the smaller channel, its possible significance cannot be discounted in view of its substantial agreement with the results of the extensive series of experiments made in the continuous-flow channel. As these two concordant series of results were obtained, however, in smooth channels of rectangular cross-section, with a water surface area remaining constant with various depths of flow, they probably would not be strictly applicable to natural streams, in which, owing to their sloping banks, the water surface area usually increases to some extent with the depth and volume of flow. In such cases, the surface rate of reaeration might tend to remain more nearly constant, or even to diminish slightly with increased depths, as may be inferred from Streeter and Phelps' observation * that in the Ohio River the rate of reaeration per unit of volume varied inversely with the volume of flow.

Effect of Sulphite Concentration on Observed Rates of Reaeration.—In the experiments made with sulphite solution in the larger recirculation channel, the concentration of sulphite was increased over that which was used in the corresponding series made in the smaller channel, the average concentration in the smaller channel being about 370 p.p.m. and in the larger channel 1000 p.p.m. As previously noted, this change in sulphite concentration was made in order to ascertain, from a fairly long series of measurements, whether a difference of this magnitude in the mean sulphite concentration would affect to any considerable extent, the comparative observed rate of reaeration when referred to the corresponding rate in pre-deaerated water under parallel conditions of flow and exposure to the atmosphere.

This comparative effect has been shown for the experiments made in the smaller channel by the results given in Table X and illustrated in Figures 7 and 8. In Figure 12 a similar comparative plot is shown of the results obtained in the larger channel experiments under identical conditions of temperature and stream depth (*i.e.* 20° C. and 12 in. depth). In this chart a consistently wider divergence between the two measured rates is revealed, as is apparently from the greater spread between the two plots.

In order to amplify this comparison, five experiments were carried

* Public Health Bulletin No. 146, U. S. Public Health Service, 1925.

out under identical flow and temperature conditions with average sulphite concentrations ranging from 220 to 1600 p.p.m. Each one of these measurements was made in the smaller channel with a water tem-

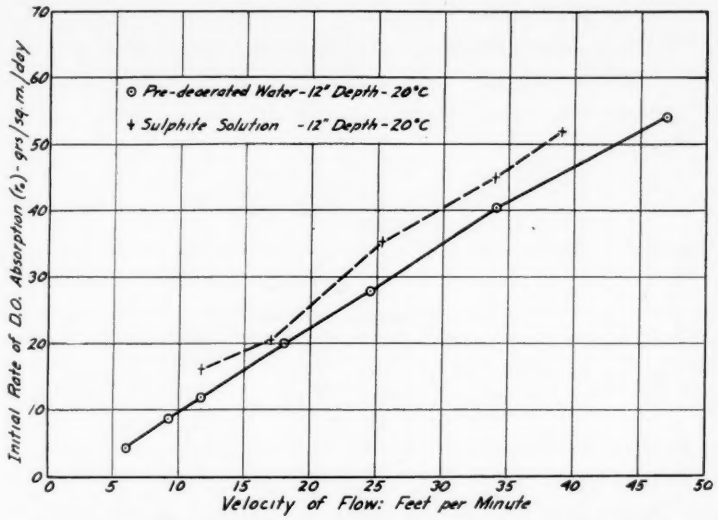

FIG. 12.—Comparative initial surface rates of reaeration observed in pre-deaerated water and in sulphite solution, from experiments in large recirculation channel.

perature of about 20° C. and a velocity of flow of 10 ft. per min., this low velocity being selected because it appeared to give the more severe test conditions for such an experiment.

The results of this comparison are given in Table XIII, and illustrated graphically in Figure 13, which is a plot of the same data.

TABLE XIII.—*Comparative Rates of Reaeration Observed in Sulphite Solutions of Varying Average Concentration, with Temperature 20° C. and Velocity of Flow 10 Ft. per Minute*

Average Na_2SO_3 Concentration (P.p.m.)	D.O. Absorbed (Gm./sq.m./day)
220	9.0
400	12.1
740	14.9
1200	15.1
1600	25.1

From these results it is noted that the rate of reaeration increased gradually with sulphite concentration up to a nearly constant level between concentrations of 740 and 1200 p.p.m. and upturned sharply from 1200 to 1600 p.p.m., indicating that the most favorable zone for observing constant rates was between 740 and 1200 p.p.m. In Figure 13, it is shown that the average concentration at which these measurements were made in the larger channel was near the mid-point of this favorable zone, whereas the lower concentration used in the smaller channel tests was in a zone of some degree of variability. The actual rates ob-

served with sulphite solution in the larger channel averaged, however, about 4.7 gm./sq.m./day higher than the corresponding initial rates observed in the same channel with pre-deaerated water, whereas those observed in the smaller channel tests were only 2.1 gm./sq.m./day higher, thus indicating that the lower concentrations of sulphite gave measured rates agreeing more closely with those observed in pre-deaerated water.

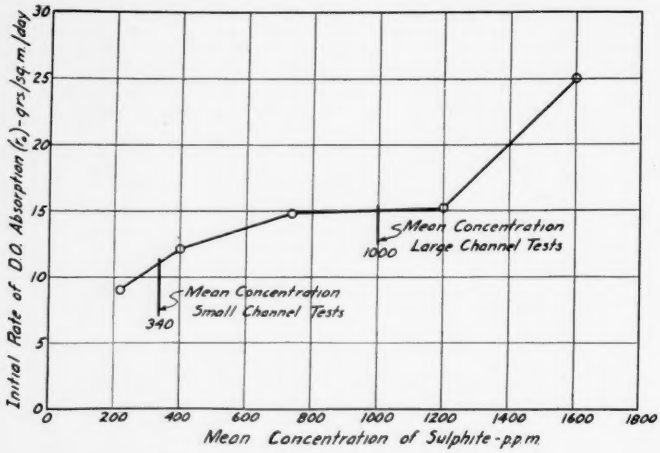

FIG. 13.—Plot of data in Table XIII.

If the plot shown in Figure 13 were taken as a basis of estimating the optimum concentration of sulphite for obtaining measured rates of reaeration consistent with those observed in pre-deaerated water, this concentration would be indicated approximately by the abscissa corresponding to a rate 2.1 gm./sq.m./day less than the rate observed at a concentration of 370 p.p.m., the average for the sulphite tests made in the smaller channel series (Table X). From the plot given in Figure 13, this concentration would be about 280 p.p.m., which represents probably the closest approximation that can be made from these data as to the optimum sulphite concentration for measuring rates of reaeration comparable to those observed in pre-deaerated water.

CONCLUSIONS

From the results of the experiments herein described the following main conclusions appear to be justified concerning the atmospheric reaeration of relatively shallow flowing streams of water, such as have been dealt with in these experiments.

1. The rate of reaeration of the underlying body of water is governed primarily by the rate of absorption of atmospheric oxygen at the water surface and secondarily by the volume of water and its temperature, depth and relative degree of agitation.

2. The rate of reaeration at the water surface appears to be practi-

cally independent of the volume of water underlying the surface, but is influenced by the temperature, oxygen saturation deficiency, and the degree of surface agitation of this underlying water. The latter is influenced, in turn, by the velocity of flow and, apparently to a slight extent, by the stream depth.

3. The existence of a direct proportionality between the surface rate of reaeration and the degree of oxygen saturation deficiency in the underlying stream has been closely confirmed by the results of the experiments. For all practical purposes, the effective oxygen saturation deficiency of a relatively shallow flowing stream may be measured with a fair degree of accuracy at a point below the surface or even at mid-depth, owing to the rapid and continuous vertical circulation of surface and sub-surface water which appears to prevail in such a stream, even when flowing in a smooth channel.

4. The effect of variations in the stream water temperature on the rate of reaeration has been shown and a basic numerical temperature coefficient has been derived agreeing very closely with one previously obtained from the results of independent measurements by Haslam, Hersey and Keen.

5. The mean velocity of flow of the underlying stream has been shown to exert a powerful influence on the surface rate of reaeration, this influence being much less, however, below a critical velocity approximating 10 feet per minute, which appears to mark the point of transition from laminar to turbulent flow in the channels used for the experiments.

6. Variations in the depth of flow have appeared to exert a slight influence on the surface rate of reaeration, possibly through their effect on the degree of surface agitation produced by a given mean velocity of flow.

7. The possibility of using weak solutions of sodium sulphite as a means of measuring directly the "initial" rate of reaeration at zero oxygen saturation has been investigated. The results have indicated both the feasibility and limitations of this method, which appears to be adapted to studying the comparative initial rates of oxygen absorption obtainable with different aeration systems and with the same system under varying physical conditions. The optimum concentration of sodium sulphite at which initial rates of reaeration closely approximating those obtainable in pre-deaerated water appears to lie between 250 and 300 milligrams per liter. The range of concentration within which the measured rate of oxygen absorption remained most nearly constant was from about 750 to 1200 mg. per liter. The rates observed in this latter range were, however, consistently higher than the corresponding rates observed in pre-deaerated water.

As all of the observations recorded in this paper were made in relatively smooth channels of rectangular cross-section, the results obtained from them might require some degree of modification if applied to conditions of flow such as might be found in rougher channels with cross-sections approaching more closely those of natural streams.

Further experiments in channels of this more natural type would, therefore, be desirable; likewise a more systematic and thorough study of the effect of depth variations on surface rates of reaeration than has been practicable in connection with the present experiments. Aside from these more obvious deficiencies, the results of this study have afforded a very satisfactory confirmation of some principles underlying stream reaeration, the validity of which heretofore has been very largely assumed. They also have yielded some additional facts which the authors believe to be of fundamental significance. Among these may be mentioned: (*a*) the derivation of a basic temperature constant governing rates of reaeration; (*b*) the indication of a definite critical velocity of flow at which the effect of turbulence becomes manifest, and (*c*) the further indication that under conditions of laminar flow, at velocities below this critical minimum, atmospheric reaeration tends to be governed very largely by the laws of hydro-diffusion, as formulated originally for this case by Black and Phelps. It also has been suggested from the data of the study that a possible direct measure of turbulence in flowing bodies of water exposed to the atmosphere may be found in their measured rates of atmospheric reaeration.

Acknowledgment

Grateful acknowledgment is made of the assistance rendered by Associate Sanitary Engineer R. S. Smith of the Public Health Service, in drafting final tracings of the charts accompanying this paper.

Editorial

THE INDUSTRIAL WASTE PROBLEM

The magnitude of the industrial waste problem has not been emphasized sufficiently to show its relation to the treatment of sewage and the prevention of stream pollution. More attention should be directed toward the lagging problem of the treatment of industrial wastes. While progress in sewage treatment has been rapid in recent years, only a few examples come to mind of the successful abatement of industrial waste pollution.

Mr. J. K. Hoskins, of the U. S. Public Health Service has drawn attention to this problem by some astonishing statistics (THIS JOURNAL, May, 1935, page 555):

"Considering organic pollution only, on the Ohio River watershed, our survey showed that the industrial wastes were equivalent to *124 per cent* of that contributed by domestic sewage. On the Illinois River the population equivalent of industrial wastes was *85 per cent* and on the upper Mississippi River *92 per cent*. It would probably be fair to say that, generally, *the organic pollution contributed by industry is about equal to that contributed by population.*" (The italics are ours.—*Editor.*)

This estimate will undoubtedly surprise many laymen but not those engineers and chemists who have had experience in the measurement and evaluation of industrial waste pollution. A few outstanding examples might be mentioned, where the effect of industrial wastes equals or greatly exceeds the effect of all the sewage of the city in which the industry is located. At Peoria, until recently, wastes from distilleries, yeast and fermentation industries had a population equivalent of more than two million, compared with a human population of 100,000; at the Chicago Southwest Side Plant, the organic content of packing-house wastes will equal or exceed the sewage from a human population of more than one million; in the paper-mill districts of Wisconsin, the influence of sulphite wastes on streams may exceed that of the sewage of smaller communities by ten-fold; Mr. C. K. Calvert (THIS JOURNAL, November, 1934, page 1164) estimated the industrial wastes of Indianapolis to have a population equivalent of 268,000 as compared with a human population of 330,000. He made the following significant observation:

"Applying the tax rate necessary to realize the actual 1933 sewage plant operation cost to the assessed valuation of the connected industries tabulated, shows that they paid a total of $878 for the disposal of their wastes for the year. On the basis of relative population equivalent, as determined from the B. O. D. results and volumes of flow, the treatment of the wastes from these industries cost $51,109. The large discrepancy in the two sums suggests that, in fairness to individual taxpayers, some middle course, at least, should be followed."

This statement indicates the inadequacy and absurdity of applying the assessed tax valuation as a measure of the cost of treating industrial waste in sewage treatment works.

The "middle course" referred to by Mr. Calvert may be taken to mean that other yardsticks, in addition to B. O. D., might be considered in the adjustment of rates for treatment. These additional or modifying factors include volume of flow, weight of suspended solids, proportion of organic matter in such solids, and scum-forming or toxic properties. Some sewer-rental ordinances take ac-

count of the volume of industrial wastes, but the strength is rarely if ever evaluated.

The rational method of appraisal should take account of all characteristics of the wastes, as reflected in the cost of handling, whether measured by volume, B. O. D., solids or toxic properties. In most cases it is possible to measure and determine accurately the volume, B. O. D., solids, and amenability to treatment. Corn products, packinghouse, tannery, food products and similar wastes can usually be handled by biological processes of treatment, although other wastes, such as ammonia-still wastes from coke plants, paint, chemical and metal-working wastes (copper) may be toxic and fatal to biological treatment. In one case, that of ammonia-still wastes, which contain from 1,000 to 3,000 parts per million of phenol, in high dilution the waste may be treated, although it has a high B. O. D., while in lower dilution the phenol may be bactericidal and interfere seriously with biological treatment. Dairy wastes, concentrated, may become so acid as to interfere with treatment, but when diluted and treated aerobically, the organic content may be oxidized at high rates.

When industrial wastes can be treated with city sewage, it is generally true that such methods result in lower cost than if the wastes are treated separately to an equal degree. Where isolated plants must treat their wastes, the problem may be more difficult but usually not so difficult as the manufacturer would have us believe. In such situations the difficulty has frequently led to intensive study of methods of re-use, re-circulation and recovery of solids within the plant. A few references to outstanding achievements in this respect are: the "bottling-up" of corn products wastes at Argo, Pekin, Cedar Rapids and Decatur; the recent installation of filters and evaporators at the Hiram Walker distillery in Peoria; the recovery of "white-water" solids in paper mills; the Howard process for recovery of sulphite and combustible solids from sulphite liquor; the extraction process for recovery of phenol from by-products coke plant wastes; the recovery of acid sludge in oil refineries; and the recovery of acid and iron from pickling liquors.

In other cases industrial wastes have been treated by sewage-treatment processes in plants built by the industries, such as: the Winslow Brothers tannery waste plant and the Bird and Company textile waste plant in Massachusetts; the various cannery waste plants in Wisconsin; the Hormel packinghouse waste plant in Austin, Minn.; the Decker packinghouse waste plant in Mason City, Iowa; and the plant for treatment of mixed dairy and laboratory wastes at Beltsville Center, Maryland.

Packinghouse wastes at Cedar Rapids and Oklahoma City are treated in the city sewage disposal plants, and an annual fee is paid by the industries to the city for the service.

Although these references indicate progress toward alleviation of the industrial waste problem, much still remains to be done. Industries are loath to spend money on treatment of their wastes, and in some cases delay has led to improved and more economical procedures. However, the time for action cannot be deferred indefinitely and with the attention of the state authorities, the Izaak Walton League, the National Resources Board and the Lonergan bill directed toward the industrial waste problem, it behooves industry to make provision for recovery or treatment of stream-polluting wastes by the best available process.

F. W. MOHLMAN

Proceedings of Local Associations

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Eighth Annual Meeting

New York City, January 14 to 17, 1936

The Eighth Annual Meeting of the New York State Sewage Works Association was held in New York City, January 14 to 17, 1936, with headquarters at the Hotel Astor. Over 200 members and guests were registered.

Messrs. Fred J. Biele (Huntington), Harry Eustance (Ithaca) and Thomas J. Smith (Newark, N. Y.) were elected to the Executive Committee for a period of three years. Mr. Linn H. Enslow of New York City was elected President and Mr. Charles C. Agar of Albany, Vice-President. A. S. Bedell, State Department of Health, Albany, was reappointed Secretary-Treasurer.

The program opened with a joint dinner of the Sanitary Engineering Division of the A. S. C. E. and the N. Y. S. S. W. A., held at the Hotel McAlpin. The principal speaker was Abel Wolman, Chairman of the Water Resources Committee of the National Resources Committee, who spoke in his usual interesting manner on problems of water pollution control.

At the general business meeting on Wednesday an amendment to the constitution was passed permitting the organization of local sections, and an application for the formation of the Long Island Section was approved. Attention was again called to the activities of the Rating Committee, and the fact that a loving cup suitably inscribed would be awarded at the Spring Meeting to the operator who presented the best report of operation for the year 1935, in accordance with the regulations of the Rating Committee.

At the technical season Earl Devendorf, Associate Director of the Division of Sanitation, N. Y. State Department of Health, Albany, presented a very timely paper on "Policies and Progress in Sewage Treatment in New York State," with particular reference to progress made in construction under Federal and State Relief Agencies. This was followed by a paper on "Progress in Milk Waste Disposal" presented by Dr. C. R. Roberts of the Sheffield Farms, Inc., New York City.

Following the luncheon President Morris M. Cohn presented the Kenneth Allen Memorial awards for 1935 to Samuel I. Zack for the most meritorious paper of a technical and research nature, and to Harry H. Hendon of Birmingham, Alabama, for the best paper on sewage plant operation presented during the year. Walter D. Binger, Deputy Commissioner of the New York City Department of Sanitation, was the principal speaker and gave a most interesting talk on the progress in sewage treatment in New York City during 1935. At the

afternoon session Harry H. Hendon presented a paper on "Chemical Treatment during 1935 at Birmingham, Alabama," which admirably supplemented the paper presented at the previous Annual Meeting. Samuel I. Zack gave a paper on "Operating Experiences at Perth Amboy, N. J." and the discussion on these two papers was opened by Messrs. F. W. Gilcreas and Linn H. Enslow. The discussion from the floor indicated the renewed interest in chemical treatment of sewage. Dr. A. J. Fischer presented a most exhaustive paper on "The Economics of Various Methods of Sewage Sludge Disposal," and John V. Fenton gave a brief paper describing the Great Neck Sewerage Project.

On Thursday the members of the New York State Sewage Works Association were guests of the Sanitary Engineering Division of the A. S. C. E. at their technical session and on Friday both groups participated in an inspection trip to the Great Neck village sewage treatment plant, arranged through the courtesy of the Municipal Sanitary Service Corporation of New York City, which furnished busses and a buffet luncheon at the plant. This unique plant provides for vacuum filtration of the sewage after pre-sedimentation, using paper pulp as a filter medium. The sludge is disposed of by vacuum filtration and incineration at a municipal refuse incinerator.

The Spring Meeting of the Association will be held at Lido Beach, Long Island, in the early part of June.

A. S. Bedell,
Secretary

THE FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Minutes of the Annual Meeting of the Board of Control

The Annual Meeting of the Board of Control of the Federation of Sewage Works Associations was held in The Engineers' Club, 32 W. 40th Street, New York City, on Thursday evening, January 16, 1936, at 7:30 o'clock, following a dinner by the twenty-one representatives attending.

The Chairman, Mr. C. A. Emerson, Jr., presided. The roll was called and the following were found to be present in person:

Name	*Representing*
H. G. Baity	North Carolina Sewage Works Association
John H. Brooks, Jr.	New England Sewage Works Association
Wm. W. Buffum	Member at Large
Morris M. Cohn	New York State Sewage Works Association
W. W. DeBerard	Central States Sewage Works Association
C. A. Emerson, Jr.	Pennsylvania Sewage Works Association
Linn H. Enslow	New York State Sewage Works Association
Charles Gilman Hyde	Member at Large
Arthur P. Miller	Federal Sewage Research Association
H. E. Moses	Pennsylvania Sewage Works Association
Wm. J. Orchard	Member at Large
Wm. M. Platt	North Carolina Sewage Works Association
Willem Rudolfs	New Jersey Sewage Conference
H. W. Streeter	Member at Large
Earle L. Waterman	Iowa Wastes Disposal Association
F. W. Mohlman	Editor

Present in person, acting as proxy:

Name	*Representing*
A. S. Bedell (for Harry C. Hall)	Maryland-Delaware Water and Sewerage Ass'n.
F. M. Dawson (for J. L. Ferebee)	Central States Sewage Works Association
Gordon M. Fair (for Roy M. Harris)	Pacific Northwest Sewage Works Association
F. Wellington Gilereas (for L. W. VanKleeck)	New England Sewage Works Association
Guy E. Griffin (for W. S. Mahlie)	Sewage Division, Texas Section, S. W. W. A.

The following were represented by proxy:

Name	*Representing*
Floyd G. Browne	Ohio Sewage Works Conference Group
H. J. Darcey	Oklahoma Water and Sewage Conference
V. M. Ehlers	Sewage Division, Texas Section, S. W. W. A.
J. B. Gordon	Federal Sewage Research Association
Max Levine	Iowa Wastes Disposal Association
J. R. Rumsey	Michigan Sewage Works Association
Dario Travaini	Arizona Sewage Works Association
Abel Wolman	Maryland-Delaware Water and Sewerage Ass'n.

Chairman Emerson reported briefly on the gratifying growth of the Federation during the past year, not only in membership but also in the improved financial condition. He referred to its expansion into an international organization, called attention to the need for further progress, stated that this was a critical time and that great care should be exercised in planning for the future, which was bright with prospects for further development.

Business Manager Buffum reported that 2063 persons were receiving the JOURNAL at the end of the year, an increase of 233 over the corresponding figure a year ago. Of this total 1678 were members of local associations, 340 were non-member subscribers, with 45 gratis and exchange subscriptions. Of the member subscribers 193, or twelve per cent, reside outside the United States, chiefly in Canada and England. Of the 340 non-member subscribers, 178, or slightly more than half, reside abroad.

Mr. Buffum, in commenting on the growth of the Federation, recalled that at St. Louis in 1927, at a meeting held preliminary to organization, effected the following year, the most optimistic estimate of the probable maximum number of subscribers to the JOURNAL was one thousand; double that number are now subscribers after only eight years existence, with bright prospects for further expansion.

Contract advertising in 1935 averaged 19⅔ pages per issue, exceeding the 1934 average of 15½ pages, which then represented the highest average since the JOURNAL was begun.

The Board by appropriate motion accepted Mr. Buffum's report and declared it to be the sense of the meeting; that because of the support given by The Chemical Foundation it had been possible for the

Federation to function and to publish the SEWAGE WORKS JOURNAL; that the Board gratefully expressed its appreciation both to The Chemical Foundation and to Mr. Buffum.

A general discussion followed. Suggestions were offered for increasing income; the desirability and necessity for securing more advertising for the JOURNAL were stressed; and consideration was given to the practicability of increasing the subscription price to members of affiliate associations, it being pointed out that to do so probably would involve changing the constitutions and by-laws of all the affiliates.

Because of the financial loss occasioned in furnishing reprints of published articles free of charge, the Board, by appropriate motion, decided to discontinue this practice. In this the Federation follows the practice of most of the technical publications.

The Secretary-Treasurer, in his report, showed that the twenty-one affiliates had a total net membership of 1667, with 33 dual memberships deducted, a net increase of 199 over the preceding year. Eighteen of the affiliates are in the United States, one in Canada and two in England. 439 new members were added in 1934, while 256 former members did not renew their membership. Nevertheless, the figures show a net gain of 183 actual new members. Of the five largest groups, New York State Sewage Works Association had the largest membership, followed in order by California, Central States, Pennsylvania and New England. On motion the report was accepted.

NEW BUSINESS

The application of the Georgia Water Works and Sewage Operators' Association was voted on and duly approved. Similar action was taken with respect to the application of the Sanitary Engineering Division of the Argentine Society of Engineers (Division Tecnica de Ingenieria Sanitaria), Buenos Aires, Argentina. In connection with this latter organization, the Board passed a resolution of appreciation to E. D. Besselievre of New York City for the excellent work done by him in bringing about this application.

The Chairman reported that he had had conferences with representatives of the Russian Sanitation and Water Works Association concerning cooperative action with the Federation and possible affiliation. After discussion, tentative authorization for affiliation was voted provided the application submitted and the relations to be established be acceptable to Chairman Streeter of the Membership Committee, and to Chairman Emerson.

Mr. Streeter reported that Dr. Mohlman and he had had correspondence with German engineers, which may lead to an application later for affiliation by a group of persons in Germany interested in the Federation. They were requested to follow up the matter.

Mr. Emerson next called to the attention of the Board the possible need for changes in the Federation Constitution and By-Laws which was adopted to govern an organization less far-reaching than the Federation has become. Upon request the Board granted the Chairman

authority to appoint a committee to study this question during the next year and to submit such revisions and changes as may appear desirable to the Board and Affiliate Associations in the manner prescribed for such action.

Editor F. W. Mohlman, in reporting on matters pertaining to the SEWAGE WORKS JOURNAL, asked for advice concerning the inclusion in the JOURNAL of a section on practical operating problems. He had in mind publication of the list of annual operation reports, the compilation of cost data, the description of practical operating kinks and similar items that would appeal to the operator of the smaller plants. It was his opinion that it would require a practical operating man to pick out the essentials of such data.

Discussion ensued as to the possibility of this move, agreement being general as to its desirability if it could be financed. It was suggested that it might be found practical to cut down on abstracts of articles in publications readily available, merely reciting title and reference, and use the space thus saved for the operators section. The matter was referred to the Publication Committee for consideration.

The Board proceeded to the election of officers and selection of committees for the ensuing year, with the following result:

Officers

Chairman, C. A. Emerson, Jr., New York
Vice-Chairman, Morris M. Cohn, Schenectady
Business Manager, Wm. W. Buffum, New York
Editor, F. W. Mohlman, Chicago
Secretary-Treasurer, H. E. Moses, Harrisburg

Members at Large

Wm. W. Buffum, New York City
H. W. Streeter, Cincinnati, Ohio
Wm. J. Orchard, Newark, N. J.
Chas. Gilman Hyde, Berkeley, Cal.
Earle B. Phelps, New York City

Executive Committee

C. A. Emerson, Jr., *Chairman*
Morris M. Cohn
H. E. Moses, *ex officio*
Wm. W. Buffum
Wm. J. Orchard

Constitutional Committees

Membership

H. W. Streeter, Federal, *Chairman*
A. E. Berry, Canada
R. E. Fuhrman, Missouri

Publication

A. P. Miller, Federal, *Chairman*
Earle L. Waterman, Iowa
John H. Brooks, Jr., New England
W. W. DeBerard, Central States
F. W. Mohlman, *ex officio*

Coordination

Chas. G. Hyde, California, *Chairman*
J. R. Rumsey, Michigan
Linn Enslow, New York

Research

Earle B. Phelps, New York, Chairman
Willem Rudolfs, New Jersey
W. S. Mahlie, Texas
Max Levine, Iowa
H. F. Gray, California

Special Committee

Finance

Wm. M. Piatt, North Carolina, *Chairman*

Members to be selected by Chairman of Federation and Chairman of Committee.

Attention was called to the fact that in 1938 the Federation will be ten years old, and suggestions were offered that a national, or perhaps an international meeting be held on this anniversary, either alone or in conjunction with one of the national groups. Discussion followed as to the feasibility and possibility of such a plan. The matter was finally referred to the Coordination Committee with a request that a progress report be submitted to Chairman Emerson in three or four months.

There being no further business the Board adjourned at 9:30 P.M. upon motion and vote.

H. E. Moses,
Secretary-Treasurer

REPORT OF SECRETARY-TREASURER, FEDERATION OF SEWAGE WORKS ASSOCIATIONS, FOR THE YEAR ENDING DECEMBER 31, 1935

The Federation closes the year with twenty-one affiliates, eighteen in the United States, one in Canada and two in England. Included in this total are two whose applications were approved provisionally at the last meeting of the Board of Control held January 18, 1935. They are Kansas Water and Sewage Works Association and Pacific Northwest Sewage Works Association, formerly named Northwest

Conference on Stream Pollution, each of whom subsequently adopted a constitution in conformity with the requirements of the Federation Constitution governing affiliates.

Two new groups have applied for affiliation, viz.: Georgia Water Works and Sewage Operators' Association, with fourteen members, and Sanitary Engineering Division of the Argentine Society of Engineers, Buenos Aires, Argentina, starting with thirty members. Chairman Emerson and Mr. Streeter have had conferences with representatives of the Russian Sanitation and Water Works Association and the German Construction Society regarding the possibility of affiliation with the Federation.

The gross total membership of the twenty-one affiliates is 1700. Deducting thirty-three dual memberships, leaves a net total of 1667, a net increase of 199 over the preceding year. The details are shown in the following analytical summary:

	Gross Mem's'p	Dual Mems.	Gross New Mems.	Did not Renew Sub. '35	Membership	
					Incr.	Decr.
Arizona S. Wks. Ass'n.	16	—	5	5	—	—
California S. Wks. Ass'n.	181	6	34	42	—	6
Cent. States S. Wks. Ass'n.	177	—	52	31	21	—
Federal S. Research Ass'n.	47	—	16	—	16	—
Iowa Wastes Disp. Ass'n.	35	—	16	6	10	—
Kansas W. & S. Wks. Ass'n (New)	23	—	23	—	23	—
Md.-Del. W. & S. Ass'n.	29	1	1	6	—	5
Michigan S. Wks. Ass'n.	85	1	26	19	7	—
Missouri W. & S. Conf.	53	—	20	38	—	18
New England S. Wks. Ass'n.	135	3	18	15	3	—
New Jersey Sew. Conf.	56	—	12	8	4	—
N. Y. State S. Wks. Ass'n.	321	15	79	34	45	—
N. Carolina S. Wks. Ass'n.	74	—	18	21	—	3
Ohio S. Wks. Conf. Group	92	—	11	5	6	—
Oklahoma W. & S. Conf.	2	—	—	2	—	2
Pacific N. W. S. Wks. Ass'n. (New)	32	—	22	1	21	—
Pennsylvania S. Wks. Ass'n.	149	5	27	10	17	—
Sew. Div.-Tx. Sec. S. W. W. A.	11	—	—	3	—	3
Can. Inst. on Sew. & San.	64	2	22	2	20	—
Inst. of Sew. Purif.—Eng.	67	—	26	6	20	—
Inst'n. of San. Engrs.—Eng.	51	—	11	2	9	—
Total	1700	33	439	256	222	39
	33				39	
	1667 Net Mem's'p				183 Gr. Incr.	

It is a matter of gratification to note a total of 439 new members during the year, only 45 of which are chargeable to the two new affiliates. At the same time 256 former members did not renew their mem-

bership. Nevertheless, the figures show a net gain of 183 actual new members.

Letters and expressions of commendation have been received concerning the important work of the Federation; particularly as to the outstanding excellence of SEWAGE WORKS JOURNAL. In this connection I quote a letter of January 3, 1936, to your Secretary from John H. Garner, Federation Secretary of the Institute of Sewage Purification, London, England, and also President of the Institute:

"I am in receipt of your notification that the Annual Meeting of the Board of Control will be held in New York on the 16th instant.

"Unfortunately, I shall not be able to attend. On behalf of the Institute of Sewage Purification, however, I send hearty congratulations on the splendid and important work which the Federation of Sewage Works Associations is carrying on. The Institute is proud to be affiliated to the Federation, and I am hoping to strengthen the bonds of attachment by inducing more of our members to become subscribers to SEWAGE WORKS JOURNAL.

"If this letter should reach you before the Annual Meeting, please convey to the Members my best wishes for the continued success of the Federation, and for their own personal welfare and prosperity during 1936."

H. E. MOSES,
Secretary-Treasurer

Operators' Reports and Suggestions

W. D. Hatfield

Editor's Note.—Dr. Hatfield has agreed to take charge of this section, devoted to the needs of the practical plant operator. It is the result of a desire to present data from annual reports and also to build up a section on operation "kinks" and laboratory aids for the operator in the field. In order to improve this needed service, managers, superintendents or chemists are requested to send annual reports and special reports to Dr. W. D. Hatfield, 249 Linden Place, Decatur, Illinois. It is also hoped that State Departments of Health will send their bulletins, or instructions to operators on the operation of sewage treatment plants; and that individual operators will write short articles or notes on improvements in tools or operation, expressly for this section of the Journal.

Dr. Hatfield writes: "It is my experience that more often than not a valuable aid to our work is lost because the operator thinks it is not very important or not worth a paper before an engineering or scientific society. This section is to be an attempt to get together those little sketches, a drawing, and perhaps two or three paragraphs about a do-dad or gadget which has greatly reduced the labor or increased the efficiency of the plant or laboratory. It is to contain those little things that you point out to a visitor as you walk around the plant but about which you would never think of writing a paper."

Usually this section will also include condensations or tabulations of the essential data in the "Annual Reports" of operation of sewage treatment works. Such reports warrant more extensive reproduction than is possible in an abstract or review, for the tables of data, month by month, tell the operator exactly what the plant has accomplished.

It is hoped that this section will catalyze or activate the interest of the treatment plant operators and that Dr. Hatfield will be swamped with material.

SUGGESTIONS TO PLANT OPERATORS

From "The Digester," Illinois State Dept. of Health

Clarence Klassen, *Chief Engineer*, Springfield, Ill.

Maintenance of Imhoff Tanks

Settling Chamber

1. Skim off surface daily, disposing of skimmings by burial or into gas vents.
2. Scrape down walls and sloping bottom with a squeegee once a week.
3. Clean slot weekly by dragging a heavy chain along its entire length.
4. If design of tank permits, the direction of flow through the settling chamber should be reversed once each month.
5. Don't be sparing in the use of the hose in washing down walls and flushing inlet and outlet channels.
6. A ½ inch mesh removable screen across the outlet weir is helpful in catching material which clogs filter nozzles and distributors. Such a screen should be kept clean.
7. Remember that the purpose of the settling chamber is to remove settleable solids. Adjustment of baffles and of outlet and inlet weirs, valves and gates may reduce cross currents or short-circuiting and give increased efficiency. Study your tank.

Sludge Chamber

1. A pH value of from 7.2 to 7.6 should be maintained in the sludge chamber for good digestion. If the sludge has a very low (under 6.6) or very high pH (over 8.0) the gas vent contents become light and foamy and may boil over the tank walls. This con-

dition is called "foaming" and is usually caused by industrial wastes (milk plant or brewery) which turn sour quite rapidly in Imhoff tanks. May also be caused by drawing too much sludge, abrupt changes in temperature or by overloading of the sludge chamber.

In case of foaming, the cause should be determined and removed if possible. Corrective measures are: putting the tank out of service temporarily (only if another unit is available for use), drawing a small amount of sludge, the addition of lime solution to the sludge chamber to correct a low pH, and hosing down the gas vents.

2. Sludge should be removed before it accumulates to within 18 inches of the slot. The top of the sludge level may be found by the use of a pitcher pump with flexible hose suctions or with a sludge sampling device consisting of a stoppered bottle fastened to the end of a 1- by 2-inch pole, 15 or more ft. long, with a stiff wire attached to the stopper, which can be pulled at a selected depth.

3. Sludge may be removed in small quantities at frequent intervals or removal may be controlled by relative capacities of sludge chamber and sludge drying beds. Always draw at a slow rate and never remove all of the sludge in the tank or foaming will follow.

4. If sludge does not flow when valves are opened, the flow may be started by hosing or rodding through the sludge pipe connection usually provided for that purpose.

Gas Vents

1. Prevent excessive scum accumulations and keep scum moist and loose so that gases may escape easily. This may be done by hosing, by pushing the accumulations down with a rake or hoe, or by pumping the liquor which overlies the sludge onto the surface of the scum by means of a portable pump.

2. If scum formation is very thick it may be removed manually to the sludge drying bed, or pumped from vents to beds with a diaphragm type pump.

3. See "Sludge Chamber" for foaming in gas vents (above).

SPRINKLING FILTERS

Question: How can surface clogging or "pooling" of sprinkling filters be corrected?

Answer: There are several ways of controlling pooling, among which are:

1. Turn over the stone in the ponded areas with a spading fork, taking care not to handle the stone too roughly.

2. Flush the surface of the stone with water under pressure.

3. Applications of heavy doses of chlorine or chlorinated lime to the sewage in the dosing tank is effective in eliminating pools. Chlorinated lime may be ordered through the local druggist.

4. Placing a portion of the filter out of service for about 48 hours. Before this is done, however, the condition of the outlet stream should be considered and other measures employed if there is not sufficient dilution to prevent objectionable stream conditions.

5. Some filters are built in such a way that they can be flooded to a level above the stone surface and this should be beneficial in stopping pooling in many cases.

Question: How can sprinkling filter flies be controlled?

Answer: An excellent article on this subject is contained in Volume 6, No. 5 of SEWAGE WORKS JOURNAL.

Practical control methods are:

1. Completely flooding the filter for a 24-hour period about every 10 days during the fly season. This should only be done where the filter was designed for this practice.

2. Closing the valves on 2 adjacent distribution laterals at a time for a period of 48 hours so that the entire bed will be dried out by sections may give some reduction in flies.

3. Intermittent heavy dosages of chlorine through the spring and summer months is often effective. Weekly applications giving a residual of 3–5 p.p.m. are recommended.

4. The adult flies may be destroyed by burning them with a blow-torch as they rest. A spray comprised of ¼ to ½ pound of pyrethrum flower mixed with one gallon of kerosene and left standing for 24 hours with occasional stirring is very effective in controlling the adult fly but care should be taken to see that as little as possible of the spray reaches the filter stone.

A NEW TYPE OF BAR SCREEN

By A. L. Gail

Supt., North Shore Sanitary District, Highland Park, Ill.

Bar screens in small sewage treatment works are usually troublesome. They are necessary to protect pumps, by removing large objects such as sticks and wire, but in addition they catch rags, paper and fibers which need not be removed. In fact, in my experience I have found that it is desirable to allow rags and paper to pass to the pumps, or directly to settling tanks if the flow is by gravity, rather than to attempt to catch such material on a bar screen. A bar screen, during cleaning by rakes, may pass wads or lumps of solids, which may either cause valve trouble in pumps, or form balls of undigested sludge or scum in the digestion compartments of Imhoff tanks. On the other hand, if such material is taken just as received, the rags will not tend to become matted but will deposit in small pieces and will break up quickly when digested.

I would in general prefer to have no coarse bar screens preceding the plants of the North Shore Sanitary District, but it is necessary,

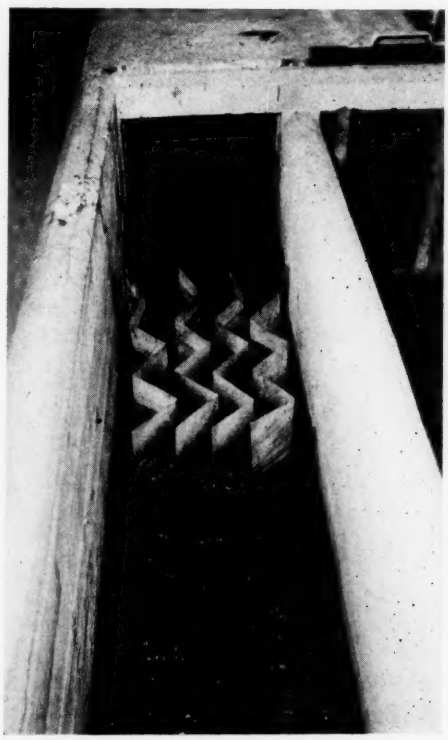

Fig. 1.—Zigzag screen at Ravinia.

however, to protect pumps and tanks from sticks, two-by-fours, etc., which will get into sewers. In order to catch such objects, but to pass rags, paper, etc., I have tried out a new type of coarse screen or rack at the Ravinia Imhoff plant. This screen is a home-made affair, constructed of 12-gauge galvanized sheet iron. A picture of the installation is shown in Figure 1. The zigzag sheets, standing vertically, are constricted at the downstream end, so that a stick which may enter the upstream end will get wedged in between the sides of the screen and be caught. The rags pass through, and although they may get caught temporarily by wrapping around the upstream edge of the screen, usually the whipping motion of the water current will loosen the strands and they will be carried through the screen.

TABLE I.—*Loss of Head, 27-Inch Channel, Ravinia Plant*

Screen	Date 1936	Hours since Cleaned	Loss of Head Inches	Rate of Flow M.G.D.	Remarks
Bar	Feb. 18	24	9.0	0.62	
1½-Inch Openings	19	24	10.25	0.62	
	19	6	7.25	0.60	
	20	18	9.5	0.68	
	21	24	10.0	0.60	
	22	24	11.0	0.60	
New Type	Feb. 22	0	1.6	0.68	Clean
9-Inch Openings	23	20	2.0	0.68	
(Upstream)	24	24	5.0	1.81	
	25	24	4.5	2.06	

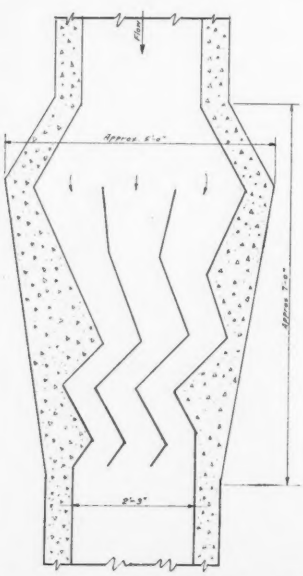

FIG. 2.—Plan showing screen installed in enlarged channel.

The former bar screen at Ravinia, with openings of 1½ inches, had to be cleaned daily, and at times of storms the plugged screen caused a large loss of head. The new screen, which was installed in September, 1935, will remain open for two weeks or longer, and even after that time only a few rags are caught on the upper edge of the screen. Sticks have been caught up to three feet long and they are easily removed. A record of the loss of head with the bar screen and later with the zigzag screen is shown in Table I. The sewage flow increased greatly during the latter measurements due to melting snow, nevertheless the loss of head was still much less than with the bar screen.

The disadvantage of the Ravinia screen is that the channel has been constricted, as shown in the photograph (Figure 1). For this reason it might be desirable to install the screen in an expanded section of the channel, as shown diagrammatically in Figure 2. The screen at Ravinia is made of light material, for temporary use, but for a permanent installation the screen walls would have to be made of heavy metal resistant to sewage corrosion. Stiffening and anchorage of the walls can be accomplished by a cast-iron rigid framework.

I believe this type of screen or rack is very satisfactory for sewage plants for there is practically no maintenance or operating cost. The screen can easily be installed in the influent trough of many operating plants.

SLUDGE DEWATERING ON DRYING BEDS *

By C. H. Young

District Engineer, Pennsylvania State Health Dept., Harrisburg

When a well digested sludge is drawn to the drying beds it continues to gasify, and within several hours a considerable portion of the sludge solids will raise to the top and the dirty sludge water will remain below. As this water drains away the floating sludge subsides. For all practical purposes the two phases of sludge drying are, *draining* and *evaporation*. With the continued loss of moisture, cracking of the sludge surface begins and, if the sludge is left on the bed long enough, this cracking will extend the depth of the sludge. Sludge with a moisture content of about 80 per cent is no longer liquid; sludge can be removed from the bed when the moisture content decreases to between 70 and 78 per cent, but a much better handling material will be secured if the moisture content is about 65 per cent, or even less.

In order to better understand the phenomena of drying as related to drainage and evaporation, data on the rate of drying for different sludges are shown in Figure 1. These curves clearly show that drainage occurs principally in the first 24 hours and is more important from the standpoint of removing the most water. On the other hand, from the standpoint of time required on the bed, evaporation is more important.

* Presented Before the Ninth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 25, 1935.

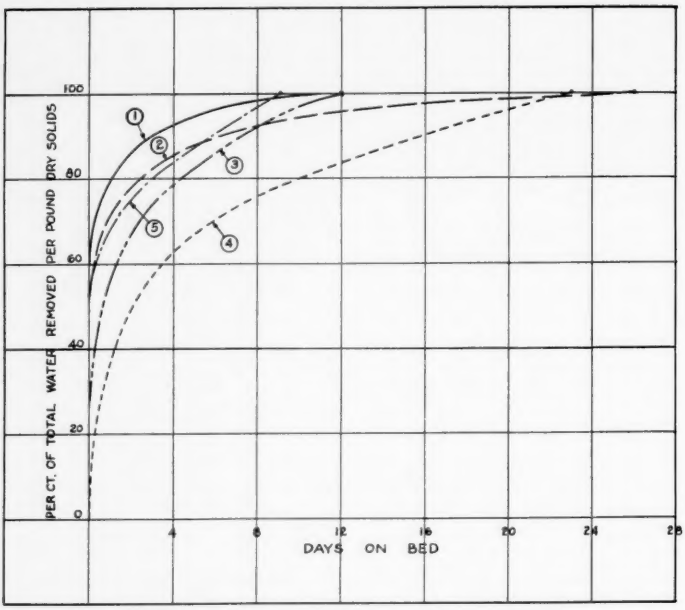

FIG. 1.—Rate of sludge drying on open and covered beds based upon tests showing the percentage of the total water removed which left the sludge at the end of a given time.

Place	Reference	Type Bed	Depth Wet Inches	Per Ct. Water		Time of Test
				On	Off	
(1) Schenectady	*Eng. News Record*, Sept. 1932	Open	10.0	95.0	65.0	Summer 1932
(2) Butler		Glass covered	9.3	92.3	76.0	Feb. 1931
(3) New Jersey	*N. J. Sew. Wk. Assoc.* 1931	Glass covered	9.0	93.8	65.2	Mar. 1930
(4) Sharon		Glass covered	11.1	86.6	64.85	May 1931
(5) Plainfield	N. J. Ag'l. Sta. Bul. 502	Open	9.0	93.8	75.	June 1929

The practical value of these curves is to show the importance of having a well digested sludge that will give up its water readily; the importance of clean, porous, draining material; the need for levelling and of seeing that the sand surface is well loosened before applying the sludge; and, where open beds are provided, of gauging the drawing of sludge as not to let a heavy rain fall on the sludge, beating it down and sealing the voids near the surface of the sand, before the initial draining is nearly completed. Likewise, if glass covers are provided and it is necessary to draw sludge during freezing weather, to close the build-

ing until the initial draining is completed, or even to delay the drawing for several days until there are more favorable temperatures. Since it requires a considerably longer time to effect evaporation, the curves show the importance of having glass covers designed to promote efficient air displacement and of properly operating these to permit the evaporating moisture to be removed from the greenhouse.

The amount of work which sludge beds will do depends upon area and condition of drying beds available, temperature, humidity, wind velocity, character and age of the sludge applied, and moisture content of the sludge as removed from the beds. The work accomplished by sludge drying beds should be expressed as pounds of dry solids per square foot of drying surface per unit of time.

From a study of available results on the operation of open and glass-covered sludge beds one can secure a wide range of results. For a 12-month period, one section of an open and one section of a glass-covered sludge bed at the Meadville sewage plant have been dosed and the sludge removed as frequently as possible. Table I gives the results of this parallel operation.

TABLE I

	Open Bed	Glass Covered Bed
No. doses	11	19
Av. depth, inches on	10.8	10.1
Av. depth, inches off	4.4	4.1
Av. % H_2O applied sludge	92.5	93.1
Av. % H_2O removed sludge	68.1	70.3
Av. temperature, deg. F.	50.1	50.1
Rainfall, inches	36.2	36.2
Lb. dry solids per sq. ft. sand surface	48	71
Lb. vol. solids per sq. ft. sand surface	24.5	36.2

These results show that the glass covered bed test section handled about 1.5 times as much dry solids per unit of area as the open bed test section.

It is surprising when analyzing the records of many plants to find that few sludge beds are worked to their capacity. There are probably many reasons for this, and the following suggestions may be of value to the operator in more effectively utilizing the available drying beds:

1. A good sludge is essential for rapid dewatering. The stage of decomposition of the solids affects its ability to drain. Control the operation of the digesters so as to produce a well digested, rapidly dewatering sludge. Remember, the more water removed by drainage the less by evaporation, which means reduced drying time.

2. Clean the bed of previously dried sludge before re-dosing, and see that the sand surface is well loosened before each dose. Never discharge wet sludge to a bed containing dry, or partially dry, sludge.

3. Provide a definite operating schedule for regularly drawing sludge to the beds. A small number of beds dosed regularly is better than a large number dosed at one time. The schedule must consider the

type of beds, open or closed, character of sludge, and the season of the year.

4. The optimum depth to which to apply wet sludge will vary from 7 in. to possibly 16 in. dependent upon the season of the year, the moisture content and the character of the sludge. This will need to be determined for each plant.

5. Level the sludge beds as frequently as needed.

6. Remove dry sludge from the beds as promptly as possible. Do not try to produce bone dry sludge or keep sludge on beds until very low moisture contents are reached unless large bed areas are available. Remember, the purpose of sludge drying beds is to reduce the moisture content so the sludge can be conveniently removed.

7. For open beds, select sludge dosing times so as not to precede a rain, if possible, and for glass-covered beds avoid drawing during excessively cold periods of the winter.

8. Provide plenty of ventilation for glass-covered beds.

9. Do not draw sludge from the digester at a discharge rate high enough to produce funnelling, thereby loading the bed with excess water to be handled.

OPERATION OF THE NORRISTOWN SEWAGE TREATMENT WORKS *

By Frank B. Altemus

Chief Operator, Norristown, Pa.

The Borough of Norristown, Pa., completed a sedimentation plant, with separate sludge digestion, during the spring of 1932. The sewage to be treated enters through a 30-inch main, equipped with a 30-inch valve. After passing the bar screen, it flows through the grit chamber and then on to the suction well. At this point it must be lifted 20 feet to the settling tanks. From the entrance to the influent end of the settling tanks, the equipment is housed in a single, roofed building—presenting a very compact appearance to the casual observer.

Four primary settling tanks provide a retention period of 2.5 hours at a 5 m.g.d. rate. The present rate of flow is 3 m.g.d., with a morning peak load of 5 m.g. After leaving the settling tanks, the effluent passes into two contact tanks which afford a further 20-minute settling period. The chlorine dispenser is located between the effluent end of the settling tanks and the influent end of the contact tanks. The solids which are left in the settling tanks are pumped to the digestors, from which, after thorough digestion, the material is run onto sand beds by gravity. Upon these it is allowed to dry.

Management and Personnel

The chief operator is directly responsible for the operation of the sewage plant, reporting to the chairman of a councilmanic Committee

* Presented Before the Ninth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 25, 1935.

on Public Works by means of monthly and a yearly report. Fixed operating expenses, of course, are: salaries and wages for the personnel, insurance premiums, and power bills. The combined salaries—including in addition to the stipends of chief operator, three shift operators, and a laborer, the cost of whatever extra labor proves necessary—approximate eight thousand dollars annually. Electric power service for a one year period totals five thousand dollars, and included in that figure is a charge of several hundred dollars for gas consumed by pilots on boilers, in the laboratory, and in one hot water heater connected to the shower bath installation. The insurance premiums for one year total $1,000 and cover loss incurred through wind and storm, explosion, and mechanical failures. The total for all the above charges is $14,000. An additional $1,500 takes care of miscellaneous items, such as spare part purchases, maintenance, replacements, lime, etc. Thus, the total of the year's tentative budget is approximately $15,500.

Operation

Bar Screen.—This intricate piece of mechanism does a definite job—and does it well. With the aid of a little electrical relay, it is only necessary to tell the screen to function every 30 minutes and with nothing other than a bi-monthly inspection of its contacts, cables and drums and a weekly greasing and oiling in the way of attention, it will remove screenings from the rushing sewage stream at the rate of 8.5 cubic feet per day. The cables deteriorate in time and must be replaced. During the first year of operation, considerable difficulty was experienced with the copper contacts and pigs on the electrical equipment. This trouble was directly due to the H_2S concentration in the grit chamber. A large contributor to this condition was the supernatant liquor from the digestion tanks. Two factors were involved in bettering this condition; one was the installation of a ventilating fan, and the other was the healthier condition of the digestion tanks.

Grit Chamber.—Grit and cinders are removed by means of compressed air, a circular well, and a washer. The air is supplied by a Nash HyTor unit driven by a 7½ H.P. motor. The well has a conical shaped bottom and a circular rim. When air is applied to the cone, the sewage is forced through a pipe to the washer. The washer, with a de-hydrating screw set at a definite angle, removes the accumulation of grit to a container. Experimentation has enabled the operators to schedule the grit removal for the most opportune time—daily, at average load hour. The original setup permitted too many screenings to flow through the screen. The solution to this problem was the installation of a suitable baffle in the rear of the bar screen. This unit, as a whole, gets weekly inspection.

Suction Well.—An inadvertent omission of an inspection or two so quickly and forcibly demonstrated that the float rods, used to vary motor and pump speeds in relation to sewage flow rate, were subject to caking with fats and greases, that a very rigid weekly inspection

schedule for this unit was immediately inaugurated, for reasons other than those of convenience.

Motors and Pumps.—The two 30 H.P. and the two 20 H.P. motors are air-blown, wiped, cleaned and greased once monthly. Twice yearly a complete oil change in all bearings is made. The Buffalo pumps, two with capacities of 2,100 g.p.m., and two with 1,400 g.p.m.—a total of 10 m.g.d., get a daily inspection for excessive temperatures and water pressure on packing glands. Two interesting changes, from a plant angle, occurred on the 30 H.P. motors and the sewage pumps. Considerable heat and vibration was noticed between the crown bearing and the packing gland on the pumps. The shaft was reinforced with a sleeve, water under pressure was substituted for grease at the packing gland, and the vibration ceased, temperature was normal and only a reasonable amount of packing was required.

The changes required on the motors consisted of new slip-ring heads and brush riggings. The radius of the slip rings was too small, causing the rings to become pitted. The brush rigging was too frail in construction, and would not permit a suitable adjustment of tension on the brushes. After one year of operation and many headaches, we sold the manufacturer on the idea of supplying new heads and rigging free, if the operating force made the necessary changes.

Auxiliary Power.—A 120 H.P., 4 cylinder gasoline motor is used to drive a 70 K.V.A., 440 volt, 60 cycle auxiliary generator. On two occasions, to date, failure of the commercial power supply has forced us to fall back on this unit for operating current. And it responded nobly. However, the periods of interruption were neither embarrassing nor of long duration. As a precautionary measure, weekly test runs of our auxiliary generating system are made.

Settling Tanks.—The four oblong settling tanks, each 90 ft. long, 17 ft. wide and 18 ft. deep, are equipped with Link Belt straight-line sludge collector units. Other than a bi-monthly greasing, cleaning and inspection, these, we find, need little attention. The collectors are started two hours prior to removal of sludge from the tanks, experimentation with shorter and longer periods having demonstrated that this is about right. By means of hoppers and a valve with hydrostatic head, the sludge is removed to wells, approximately 17,000 gallon being taken from a 3 m.g.d. flow of sewage. At present, we use an average of 100 pounds of lime—in a milk of lime solution—every 24 hours.

Digestion Tanks.—In the first year of operation, we called these tanks many names—but never digesters! The fresh sludge, as it enters the well, is automatically pumped to the digestion tank—a 400 g.p.m. pump driven by a 5 H.P. motor proving admirable for the purpose. Our plant is equipped with two batteries of such tanks—three tanks to a battery—and each battery has its 400 g.p.m. pump. The cutters installed on the non-clogging sludge pumps also helped to improve the situation. The tanks are 90 ft. long, 13 ft. wide and 21 ft. deep. Gas collection facilities are provided. We have very good re-

sults with our gas collection and consumption, all things considered. The yield has been very good, and the leaks plentiful. The large amount of water, plus the sulphide content, is our chief aggravation in this department. Due, partly, to our inability to maintain high flue gas temperatures, we have condensation troubles in the flues and boilers. With commercial gas, it is possible to operate the boilers a year with one cleaning. The sewage gas, by contrast, demands a boiler cleaning every three months.

Sand Beds.—There are 16 sand beds, each 125 ft. long and 12 ft. wide, eight of which are under glass and eight uncovered. Digested sludge flows over these from front to rear in a 6-inch deep layer which dries to a thickness of about 2 inches. In 1934 we produced 60 such beds of sludge. The Borough of Norristown is the county seat of an agricultural county, and this causes the disposal of the finished product to become a simple operation. The farmer makes application for one or more beds of sludge, at five dollars a bed. It is understood that this order is for the material in the enclosed house. To show our good faith we include, free, the sludge from one of the open beds with every covered bed purchased. This has a tendency to unload the uncovered beds which would be embarrassing if they could not be emptied, and also promotes sales. We have interested nurseries, golf courses, and care takers of estates. The farmer removes the material with his own laboring force and equipment. If a farmer becomes elated with the results of our product on, say, tomatoes and corn, we will disagree and claim we can't believe such a thing possible. The farmer becomes even more elated, trots in a goodly amount of his vegetables as free samples and proof, and purchases another bed!

Records

A daily log book, in which temperatures, visitors' names, and other data are entered, is religiously kept. The Penna. Dept. of Health report duplicate affords an excellent record on past operation for reference. All meters—gas, flow, elevation and electric—are read daily at midnight and all readings are recorded. Facts gleaned from the records of these readings, plus a power survey made by the plant operating force, made possible an annual saving of $1,100 in the electrical power bill. This survey was based on the known fact that electrical equipment of the induction type with a low power factor may be very inefficient. In our case readings were taken on the electrical equipment every hour. This continued until a representative load curve was made. A capacitor of correct size and voltage was installed by the operating force, and the efficiency read 99.5 per cent. The Philadelphia Electric Company made a check on the operation and rated the power bills accordingly.

When you visit Norristown, visit our plant. Inspection of our equipment will do you a lot more good than anything we can hope to set down on paper. Come around and look us over.

Reviews and Abstracts

H. W. Streeter

STRENGTH OF SEWAGE

By M. Lovett and J. H. Garner

Paper presented before the Public Works, Roads and Transport Congress, November 22, 1935, and reviewed, with discussion, in *The Surveyor*, **88**, 601–03 (November 29, 1935), 88, 727–28 (December 27, 1935) and **89**, 45–46 (January 10, 1936).

Determination of the strength of sewage is important particularly in connection with the preparation of treatment costs, where it is desirable to show separately the cost and degree of purification for each process. This involves the use of reliable methods of analysis of the influent and effluent of each stage of the treatment process. The present paper discusses the various methods of determination of sewage strength which have been suggested from time to time and presents a considerable volume of data collected in a study of their relative values. The "strength of sewage" is defined as "the amount of oxygen required for the complete, or practically complete, oxidation of its organic matter. The 'strength' of sewage is measured in terms of the oxygen required to oxidize its organic matter and ammonia biochemically."

Because biochemical oxidation requires a long time for completion and although the 5, 10, or 20-day demand gives useful information, more or less rapid chemical tests have been adopted in substitution of the "long aeration" method. These determinations include:

(*a*) The oxygen absorbed from potassium permanganate and potassium dichromate under various conditions of time and temperature.

(*b*) The content of organic carbon, ammoniacal, albuminoid and organic nitrogen.

Each of these estimates has its own significance but not one has been considered adequate for determining quickly the total oxidizability. The procedures are described in considerable detail.

Biochemical Oxygen Demand.—The B.O.D. of a sewage is defined as the amount of oxygen taken up from solution by aerobic bacterial action after any given interval of time. The ultimate or total demand of sewage is the amount of oxygen required for complete stabilization of the contained organic matter, which is the value compared with those estimated by chemical determinations.

The dilution and the direct, or absorption, methods for determination of B.O.D. are discussed in some detail. For the latter procedure Sierp has designed a convenient apparatus which, with the addition of a constant pressure arrangement as devised by the West Riding Rivers Board, enables ready calculation of results. The authors explain the method of working this equipment and the procedure for computing the B.O.D. as previously described by Symons and Buswell (*Ind. and Eng. Chem., Anal. Edition*, 1, 214–15). Generally somewhat higher values are obtained for effluents by the absorption method, although the results are always comparable with those of the dilution method when a buffered dilution water is used. For crude sewage the 5-day B.O.D. is often higher by the dilution method. The direct method has numerous advantages, however, in that errors of dilution are eliminated including those of estimating the proper dilution to be made, many dilution bottles are avoided, the apparatus is simple to use and can easily be refilled with oxygen if necessary and the method is equally applicable for all types of concentrated wastes.

Oxygen Absorbed from Permanganate.—Both acid and alkaline-permanganate methods, all of which have had a fairly wide application, were examined. Of the former, the West Riding Rivers Board procedure is as follows:

"150 ml. of distilled water and 10 ml. of 25 per cent sulphuric acid are placed in a 12 oz. stoppered bottle and warmed to 80° F. (26.7° C.) in an incubator. A suitable quantity of the sample, 10 ml. in the case of a crude sewage, and 10 ml. of N/80 potassium permanganate solution are then added and the mixture incubated at the above temperature for 4 hours. An excess of at least 5 ml. of permanganate is always maintained by the addition of further portions of 10 ml. of permanganate during the four hours if necessary. After the four hours have elapsed, 2 ml. of 5 per cent potassium iodide solution are added and the liberated iodine titrated with N/80 sodium thiosulphate solution, using starch as indicator."

Variations of this procedure described include those of the Ministry of Health (Methods of Chemical Analyses as applied to Sewage) and of Thresh, Beale and Suckling in their book, *Examination of Water and Water Supplies,* 1933. The Royal Commission Method (*Royal Comm. on Sewage Disp.,* 4th Report, Vol. 4, Pt. 5, 37), the A. P. H. A. Method and the Kubel-Tieman Method, standard in Germany, each have particular variations which are set forth.

Alkaline-permanganate methods are claimed by their advocates to have certain advantages, in that at boiling temperature a rapid and more complete oxidation is obtained and that decomposition products such as might occur in acid solution do not interfere. Of these procedures, the Schulze-Trommsdorff of German origin, the Wanklyn as employed in England and the A. P. H. A. are briefly discussed.

All of these oxygen-absorbed-from-permanganate methods exhibit great divergencies. The English "low temperature" procedure requires careful temperature regulation for considerable periods of time, in comparison to the "high temperature" or boiling procedures, which, however, invariably yield higher results because of more complete oxidation.

Oxygen Absorbed from Potassium Dichromate.—Adeney and Dawson (*Proc. Royal Dublin Soc.,* **18** (N. S.), 199, 1926) suggested a procedure later improved by Abbott (*Ind. and Eng. Chem.,* **19**, 919) employing acid-potassium dichromate solution for the oxidation of organic matter in sewage. Concentrated sulphuric acid is essential for complete oxidation.

Estimation of Organic Carbon.—Because the first stage of the B.O.D. reaction is largely concerned with the oxidation of carbonaceous matter, the determination of organic carbon is of special interest. The carbon dioxide resulting from the oxidation of carbon after inorganic carbon has been removed is measured and forms the basis for the procedure.

The chromic acid method devised by Mohlman and Edwards (*Ind. and Eng. Chem., Anal. Ed.,* **3**, 119) and the modification by Mills (*J. Soc. Chem. Ind.,* **50**, 375**T**, 1931) are discussed; the latter procedure is described in some detail and was adopted by the authors in their work. The method is fairly rapid and not difficult after a little practice.

The persulphate method devised by Osburn and Werkman (*Ind. and Eng. Chem., Anal. Ed.,* **4**, 421, 1932) and as modified by the West Riding Rivers Board Laboratory has given very satisfactory results and has been found accurate when applied to carbonaceous compounds of known composition. This method is likewise given in detail.

Nitrogen Determinations.—Although free and saline, albuminoid and organic nitrogen were determined for comparative purposes by well known methods, the authors agree with Buswell (*The Chemistry of Water and Sewage Treatment,* 1928) that the nitrogen content of crude domestic sewage is not closely related to the total oxygen demand.

Estimation of Strength by Calculation.—From examination of a large number of sewages, McGowan (*Royal Comm. on Sewage Disp.,* 5th Rept., App. 4, 1) found that the difference between the total (after three months) B.O.D. and the oxygen equivalent of the total nitrogen was quite generally about 6.5 times the oxygen absorbed from N/8 permanganate for domestic sewages. From this relationship formulae for approximate sewage strength were suggested:

$$(\text{Ammon.} + \text{Organic N})\ 4.5 + (\text{O abs'd in 4 hrs.})^{*}\ 6.5 \qquad (1)$$

$$(\text{Ammon.} + \text{Organic N})\ 3.0 + (\text{O abs'd in 4 hrs.})^{*}\ 8.0 \qquad (2)$$

$$\text{Ammon. N} \times 4.5 + (\text{O abs'd in 4 hrs.})^{*}\ 8.0 \qquad (3)$$

* From N/8 permanganate.

Another rougher approximation is obtained by multiplying the oxygen absorbed in 4 hours from N/8 permanganate by 10. If the N/80 permanganate method of the Ministry of Health is used, the result should be multiplied by 1.6 to obtain the equivalent of the N/8 value. If any other N/80 method is used a different factor is required. However, various ingredients such as sulphides, ferrous iron, sugar, glycerol or fats may completely alter this relationship as well as interfere with the N/80 test itself.

Population Equivalent.—The strength of sewage may also be estimated on the population basis or in terms of the oxygen demand in pounds per head of population per day, which is said to give a more consistent measure for purposes of plant design. Industrial wastes may also be converted into population equivalent values on the same principle.

Results.—Tabulated analytical data of 8 sewages are given, six of which were mainly domestic and two contained considerable trade waste. Two graphs show the course of the biochemical oxidation for five of the eight samples. The authors conclude that: "Until there is scientific evidence to show that there is some direct connection between the oxidizability (as determined by chemical or biochemical methods) of the organic matter of domestic sewage liquids and the amount of oxygen actually consumed in practical sewage purification, all methods of estimating strength must be regarded as relative or empirical. This is especially so with abnormal and trade sewages."

Discussion.—Mr. F. R. O'Shaughnessy (Birmingham) pointed out that the definition of strength of sewage as being the amount of oxygen required for complete or practically complete oxidation of its organic matter was at variance with current treatment practice in that removal of most of the gross impurities rather than their oxidation was the most economical procedure, reserving for the more costly oxidation processes only such impurities as could not be removed by preliminary treatment. Hence, the common practice of calculating the amount of liquid which could be treated, say, on a bacteria bed on the basis of the oxygen absorbed by the crude sewage could not be regarded as a very reasonable one. As the authors point out, for cost estimates it is, therefore, very desirable to show the cost and degree of purification for each process separately. He also stressed the limitations of chemical methods for obtaining absolute oxidation values.

Mr. J. H. Spencer (Northampton) noted wide variations between sewage strength and B.O.D. analytical results where periodic additions of toxic substances such as gas works liquors appeared in the sewage. In such instances the sewage, although more difficult to treat, was actually indicated by the B.O.D. test to be the weaker.

J. K. HOSKINS

REPORT OF THE WATER POLLUTION RESEARCH BOARD FOR THE YEAR ENDED 30TH JUNE, 1935, WITH REPORT OF THE DIRECTOR OF WATER POLLUTION RESEARCH

Department of Scientific and Industrial Research (British)

In its general report, preceding the more detailed report of the Director, the Board notes the difficulties in water supply and detrimental effects on stream pollution resulting from the low rainfall of 1933–34; stresses the importance of accurate information on the water resources of the country and refers to the serious pollution of rivers and difficulties at sewage disposal works arising from the discharge of effluents from yeast, alcohol and industrial solvents factories using molasses as raw material; also from dairies and milk products factories.

Brief reference is made to investigations in progress, which are described more fully in the report of the Director, Dr. H. T. Calvert. From this report the following notes have been abstracted with reference to current studies of sewage and allied topics.

Milk Factory Effluents.—In the earlier experiments, described in the last two annual reports, mixtures containing about 1 per cent by volume of milk were made up with water to represent effluents discharged from milk collecting and distributing depots

and from condensed milk factories. The first series of experiments was made to test the possibilities of biological oxidation in percolating filters 6 ft. deep and built up in six sections, each 1 ft. deep, placed one above another. After two weeks, a degree of 80–90 per cent purification was reached, but the efficiency then decreased owing to the accumulation of fat and other solids in the filter, which finally became clogged and useless. Preliminary fermentation of the milk mixture for one or two days in an open tank caused the liquid to become acid and the solid matter to become separated as deposit and scum. When the separated liquid was treated on the filters at a rate of 100 gallons per day per cu. yd. of material, the degree of purification increased to 98 per cent after 3 weeks and was thus maintained throughout the 14 weeks test period, with no clogging of the filters.

During the past year experiments have been continued in more detail on the combined process of anaerobic fermentation and biological oxidation in percolating filters. In one series of experiments 70 per cent of the fermented liquid was withdrawn every 24 hours and replaced by an equal volume of fresh waste, samples of the fermented liquids being examined to determine the changes occurring in the proteins, fats, lactose and phosphorus compounds and whether these changes were influenced by sludge accumulations. Decomposition of proteins was most rapid at 30° C., with the largest production of ammoniacal nitrogen. Fat decomposition into the lower fatty acids also occurred at 30° C. Organic phosphorus was transformed into inorganic P_2O_5 compounds (10–20 p.p.m.). Fermented liquids from the open tanks, when treated at the rate of 100 gallons per day per cu. yd. of filtering material, gave bright effluents with a B.O.D. of 20 p.p.m., as against 700–900 p.p.m. in the filter influent. The B.O.D. of the fresh 1 per cent milk mixtures was 1200–1300 p.p.m. giving an overall purification of 98 per cent.

From the biological examinations in the fermentation experiments, 48 species of bacteria were isolated and tested on seven carbohydrates and on the ammonium salts of formic, acetic and lactic acids. Of these 48 species, 20 occurred in two or more experiments, and only 5 were abundant. Four of these 5 species were facultative anaerobes and caused active fermentation of sugars with gas production.

Several series of experiments have been made on the treatment of milk effluents by aeration in the presence of sludge. In these experiments, aeration with revolving brushes (after Kessener) also was tried. For some tests small quantities of activated sludge from a sewage plant were added. With 0.25 and 0.50 per cent of milk in the mixture, the results were thus improved, but with 1.0 per cent, they were poorer. The brush aeration system yielded effluents having a slightly higher B.O.D. than from forced aeration, but the dissolved oxygen and oxidized nitrogen were higher in the brush effluent.

In some experiments, made by Mr. O'Shaughnessy at Birmingham, he found that by periodically changing the order of percolating filters connected in series, clogging was minimized and good results obtained. Satisfactory purification also was secured from the activated sludge process with activated sludge from sewage and a 24-hour aeration period. Over-aeration caused deterioration of the effluent. The presence of some sewage in the milk mixture was found advantageous.

Activated Sludge Process of Sewage Treatment.—In the last annual report, the results were given of experiments in which rates of oxidation of sewage, sewage sludge and other substances were measured in Bareroft respirometers. Experiments on the same lines have been continued. For the reader's convenience, the Bareroft apparatus is again briefly described.

Previous experiments had indicated that rates of oxidation shown by the Bareroft apparatus were definitely higher, on the same material, than by the ordinary dilution method B.O.D. test. The experiments made during the past year have yielded similar results in this respect. Previous observations also have been confirmed showing that the quantity of oxygen absorbed by a mixture of sewage and activated sludge is greater than the sum of the amounts absorbed by the same sewage and sludge when oxidized separately. Thus, in one experiment the total amount of oxygen absorbed by the sewage and sludge when examined separately was 287 cu. mm. and when combined was 605 cu. mm. This shows that by mixing crude sewage and activated sludge the rates

of oxidation of the sewage or sludge or both by air are greatly accelerated. From the results cited, these rates were roughly doubled by combining the two materials. From comparative experiments made with crude sewage and treated effluent, it is shown that the difference between the sewage and the effluent can be demonstrated in a few hours by measuring their relative rates of oxidation in admixture with sludge.

Several series of experiments were made with sewage in admixture with sludge previously saturated with crude sewage, with a view to ascertaining the effect on the activity of the sludges of mixing them for a short time with large volumes of crude sewage without aeration. In general, the results showed the detrimental effect of this mixing procedure, though they also indicated that when the mixture was shaken with air, the oxidizing activity of the sludge was increased.

Attempts have been made to alter the activity of sewage sludges by aerating them for several weeks with special substrates instead of sewage, including glucose, tryptic digest (amino acids with a trace of sugar) and ammonium salts. From the results it is shown that a Seitz-filtered sewage was more rapidly oxidized in the presence of normal activated sewage sludge than with any of the three special sludges, though further experiments also showed that it is possible to modify the activity of a sludge so that it oxidizes one substrate more readily than another.

Colloids in Sewage.—From the results of previous studies, it had been concluded that most of the dispersed matter in sewage is relatively coarse and can be separated by sedimentation or centrifuging; only a small proportion is in particles of sizes of the order of true colloidal sols. Experiments indicated that the dispersate has a small negative electrical charge at pH 6 and a slight positive charge at pH 2, an isoelectric region being between these two pH values.

Experiments were made on the effect of passing bubbles of air, oxygen, hydrogen and nitrogen through sewage, on the coagulation of dispersed matter. The results showed that all four gases had an appreciable effect, which was about the same for each gas. By allowing the sewage to stand undisturbed at 25° C., some flocculation resulted, but much less than with bubbles of gas. These experiments have been continued at temperatures ranging from 0° to 80° C., including tests of the effect of mechanical agitation and of quiescent conditions, with air contact excluded. Coagulation was relatively slight at 0° and 10° C., but increased with temperatures up to 80° C. The results at 80° C., in comparison with those at 37° and 25° C., tentatively suggest that the coagulation with bubbles was caused primarily by physical and chemical rather than biological action. If the action is largely physical, the question arises whether coagulation is encouraged on the surfaces of the bubbles, or whether the bubbles act mainly by stirring the sewage. The results with mechanical stirring alone show that a considerable amount of coagulation was produced mechanically by agitation, though not so effectively as with gas bubbles. Further experiments are being made to determine whether more vigorous agitation will produce increased flocculation.

River Mersey Investigation.—Progress has been made in the investigation of the effects of sewage in the River Mersey estuary on the amount and nature of solids deposited in the estuary. Estimates of the concentration of sewage, which amounts to about 40 m.g.d., have been made by two methods; one based on examinations of the estuary water for changes in salinity at various points and the other on the results of analyses for the relative concentrations of soluble carbon in the sewage and in the sea and estuary waters. A survey has been made of the sources of clay and mud deposited in the estuary. Experiments have been carried out on the rates of sedimentation, in glass cylinders and specially designed tanks, of suspensions of mud and clay in sea, tap and estuary waters and in mixtures of sea and tap waters. In many experiments, sewage was added to these mixtures to determine its effect on rates of sedimentation. Other experiments are in progress to determine the relative resistances of different samples of mud to erosion by currents of water.

Gas Works Effluents.—A committee of the Institution of Gas Engineers has issued a fourth report describing further laboratory experiments on the biological oxidation of sewage to which definite proportions of gas works liquors have been added. The sewage and mixtures were treated in percolating filters and by the activated sludge

process, the filters being built up in several sections to facilitate observing the progress of purification. The results have indicated that apparently some constituents of gas liquors, other than phenol, catechol, thiosulphate and thiocyanate are not readily oxidized in the biological processes. Phenol is readily oxidized, but thiocyanate can be oxidized only when the purification media have become adapted to this substance.

The experiments with percolating filters led to the conclusion that most of the constituents of gas works liquors are oxidized in the first sections of the filters, in which the most rapid oxidation of sewage also occurs. With the activated sludge process, the oxidation of gas liquors appears to be delayed until a proportion of the sewage has been oxidized. These conclusions are only tentative until the results can be tested by larger scale observations under conditions of operation at a sewage disposal works.

H. W. STREETER

RECENT DEVELOPMENTS IN SEWAGE TREATMENT AND DISPOSAL AT THE LONDON COUNTY COUNCIL WORKS

BY J. H. COSTE

Paper presented at meeting of the Royal Sanitary Institute, London, England, January 14, 1936, and abstracted in *The Surveyor*, **89**, 75–77 (January 17, 1936).

In 1928 the local authorities inaugurated a policy of testing the applicability of the activated sludge process to the treatment of London sewage and such experiments have been in progress since that time. The present paper discusses the most recent observations on the experimental unit designed to treat from 5 to 10 m.g.d. of sedimented effluent.

The experimental unit is of the Haworth type. The aeration channels are in two compartments, one above the other, have a total length of 6,400 ft., and are 6 ft. wide and 5 ft. deep, with a capacity of 186,000 cu. ft. Paddles at each end of the 11 channels circulate the liquid through the 66 compartments. The settled influent with about 150 p.p.m. of suspended solids is mixed with about 10 per cent of reactivated return sludge at the entry of the aeration channels. A small portion of the aerated sewage sludge mixture flows back from the 66th to the first compartment, but most of it goes to the six settling tanks arranged in parallel, three of which are pyramidal, 54 ft. square and 29 ft. deep and three are 60 ft. square and 9 ft. deep. The supernatant from these tanks is discharged to the river and the sludge is pumped to four reaeration channels each 15 ft. deep and 30 ft. long, where it is reconditioned by air diffusion through porous tiles. It is not considered necessary to produce a highly purified effluent but a stable one.

Results Obtained.—Since July, 1932, when routine operating conditions were established, 10 m.g.d. of sewage have been treated with 10 per cent of sludge, using an average of between 0.5 and 0.6 cu. ft. of air per gallon, almost entirely for reaeration. No operating troubles have been experienced and no bulking of sludge has occurred. The production of sludge, 10 m.g. per year, has amounted to about a day's flow of sewage per year. Although higher proportions of sludge gave better effluents, the greatest total effect was obtained with about 10 per cent. The small proportion of sludge wasted is ascribed to effective reaeration or rapid oxidation of organic matter in the "clarification stage."

The degree of purification effected has been considerable and with only very occasional and short periods of intensive sludge regeneration. It was found that the filtrate from a mixture of sewage and activated sludge absorbed less oxygen from permanganate than the amount calculated from the oxygen demand of the filtrates of the constituent liquors mixed in the same proportions. This "immediate" oxidation effect was confirmed by tests of the sewage sludge mixture at various stages throughout the channel system. It was found that with 7½ m.g.d. sewage flow the progressive samples showed a regular decrease in B.O.D. and in oxygen absorbed from permanganate until at about the 55th compartment no further oxidation occurred. With the 10 m.g.d. rate, a similar but less rapid decrease occurred and the latter compartments were doing more useful work than with the smaller amount. The author believes that reaeration of the

settled sludge is more effective than complete aeration of the sewage-sludge mixture. The two-tier plant has been most satisfactory and five additional units of very similar design are now under construction.

Experiments on Sludge Digestion.—Although sea disposal of sludge has been satisfactory, digestion experiments have been conducted with a view to reducing the volume to be so disposed of as well as to recover fuel gas. An experimental digester of 25,000 gallons capacity and provided with agitation, heating and gas collection equipment has been constructed. From a total of 233,000 lbs. of dry organic matter (determined by loss on ignition), 205,000 lbs. of gas were obtained or 14 oz. of gas per lb. of organic matter. Digestion was more rapid at higher temperatures and the fat content was reduced to about one third the original amount.

Emergency Treatment of Sewage During Dry Summer Weather.—To control odors near the London sewer outfalls in the summer months, use of ferric salts has given promising results. It is proposed to vary or omit this treatment according to the fresh water flow and oxygen content of the receiving stream. The manufacture of ferric chloride at the site by a continuous process of chlorination of ferrous sulphate has been demonstrated to be practical after considerable experimentation. The plant consists of:

(*a*) an apparatus for making a solution of chlorine gas in a large excess of water,
(*b*) a rotary mill in which a solution of ferrous sulphate in water is made,
(*c*) a mixing and reaction chamber into which the chlorine and ferrous sulphate are introduced.

The author considers that greatest promise of further improvement in river pollution by London sewage is "in the direction of increasing the efficiency of the preliminary operations of sedimentation and coagulation of crude sewage which has received treatment which will prevent it becoming septic before it reaches the outfalls."

J. K. Hoskins

BIRMINGHAM TAME AND REA DISTRICT DRAINAGE BOARD TWENTY-FIRST ANNUAL REPORT, 1934–5

The district serves a population of 1,200,000 and has an average dry weather flow of 41,700,000 Imp. gals. per day. In October, 1934, the Coleshill Sewage Works was opened. The present plant when completed will serve a population of 67,000 and will have cost £150,000. The site is large enough for five such units. It is expected that the second unit will be required within a short time and the power house and compressor house have been built sufficiently large to accommodate the equipment for two such units. The pump houses at the storm water tanks and sludge drying area are large enough for the ultimate plant of five units.

At the Minworth Works pumps and mains have been installed to give a portion of the sewage double treatment on the bacteria beds. At present seven acres for the beds are being equipped with mechanical distributors in place of fixed spray nozzles and twelve additional settling tanks are being provided.

The total cost of treatment per rated tenement, including interest and repayment of bonded indebtedness, has been reduced from 14 shillings 8½ pence in 1922–23, to 12 shillings 2 pence in 1935–36.

R. S. Smith

EXPERIMENTS WITH MODEL TANKS

By W. Clifford and M. E. Windridge

Presented at a meeting of the Midland Branch, Birmingham, March 9, 1935. *Journal and Proceedings of The Institute of Sewage Purification*, Part I, 1935, pp. 136–150.

This study had for its object the finding of a method for comparing the effect of shape and capacity of tank upon the rate of settlement of suspended solids. To avoid the difficulties of observations on full scale tanks, use was made of model tanks, employ-

ing the relationship between such models and their full scale prototypes as worked out by others, namely, that the retention periods vary as the square root of the lineal dimensions.

The experimental tank was made to 1/50 of the scale of the Wolverhampton tanks and hence the retention period was assumed to be $1/\sqrt{50}$ or 1/7 that of the large tank. All liquids were fed to the model at a constant head in any experiment to maintain a constant flowing-through time. Preliminary determinations of this rate of flow were made by adding a weak salt solution continuously to the inflowing liquid until the concentration of salt in the effluent was the same as in the influent. Two distinct and typical kinds of curves were thus obtained—one a steadily rising one indicating considerable mixing, obtained with high inlet velocities (narrow inlets) or low nominal retention periods; the other an S-shaped curve, indicating less general disturbance, resulting from low inlet velocities and high nominal retention periods. The nature of such curves, therefore, was of service in indicating the extent of mixing caused by various types of inlets. From these experiments, the following conclusions were drawn:

" (1) That the physical characteristics, particularly the density, of the liquid passing through a tank, and their changes have a preponderating influence on the manner of flow of a liquid through a tank.

" (2) That, other things being equal, settlement will probably be the greater, the less the velocity of the liquid at the point of entry into the tank.

" (3) That increased velocity of flow in the tank consequent upon a reduction in the nominal retention period will probably cause a considerable decrease in the amount of settlement, even with a well-designed inlet.

" (4) That the methods of experiment so far used are not capable of exact correlation with the behavior of suspended matter under practical conditions."

Suspended Matter Experiments.—Precipitated chalk was used to determine the extent of settling out of suspended material under different conditions of flow, because it settles out of suspension in water in much the same manner as sewage solids and can be easily separated and weighed. Although direct percentage removal is the simplest form of expression for the results, it is not the best because a standard of reference is required to which all samples may be referred. The Steurnagel method was adopted, based on the principle of settling, under quiescent conditions, a similar sample to that used in the tank and comparing these results.

For the quiescent settling vessel, a 500 ml. cylinder was used, giving a column of liquid about 25 cm. by 4.5 cm. diameter, and the top 100 ml. of liquid was arbitrarily employed for determination of the degree of settling effected. Furthermore, because the concentration of the suspended matter has a marked effect on the rate of settlement, as shown by an illustrative graph, the liquid in the cylinder was kept as near as possible identical with that treated in the experimental tank. With these precautions, the efficiency of sedimentation of the tank was obtained from the ratio:— Amount of solids removed in the tank, divided by the amount of solids removed by quiescence in time equal to the nominal retention period. The principal results obtained thus far are presented in the following table:

Nominal Retention Period		1 Hr. 10 Min.	2 Hr. 20 Min.	3 Hr. 30 Min.	7 Hrs.	14 Hrs.
Inlet	Outlet	% Efficiency				
Overflow weir	Overflow weir	71	68	72	83	95
Three 21-in. tees	" "	82	83	85	98	91
Three 19-in. pipes	" "	69	68	68	90	89
Three 19-in. pipes and standard eddy buckets	" "	92	70	80	87	97
Three 19-in. pipes and large eddy buckets (11 ft. 3 in. × 5 ft. 4 in.)	" "	84	76	83		
Three 14-in. pipes	" "	46	56	61	70	92
Three 14-in. pipes and standard eddy buckets	" "	55	69	90	92	95

Conclusions.—" (1) That at high retention periods (14 hours) good settlement may be obtained irrespective of the nature of the inlet, the minimum efficiency so far obtained at this rate of flow being 89 per cent. Of course, the effects of other circumstances, for example, septic action, are not being considered.

" (2) That with simple pipe inlets the efficiency drops off rapidly as the size of the inlet or the nominal retention period is reduced. This is entirely in agreement with the conclusions suggested by the salt curve experiments.

" (3) That an eddy bucket placed over a pipe inlet produces a very distinct improvement in the efficiency. This agrees with the idea previously put forward, that rapid dissipation of the kinetic energy of the inflowing liquid is necessary if good settlement is to be obtained. We may explain that the term 'standard eddy bucket' used in the table refers to an eddy bucket of which the dimensions with reference to the diameter (d) of the inlet pipe are—diameter of bucket $2\frac{1}{2}$ d and depth 5 d. These dimensions are the same as have been adopted in practice for vertical flow tanks. We hope to investigate further the effect of the size and position of eddy buckets in horizontal flow tanks.

" (4) Three 14-in. inlets may be taken as quite a large inlet area for a tank of this size, according to common practice. The results show that this area may be considerably increased with advantage especially if retention periods of seven hours or less are to be dealt with.

" (5) It will be noted that certain of the figures in the first column of the table are anomalous, there being a jump in the efficiency for 1 hour 10 minutes retention as compared with 2 hours 20 minutes. The reason for this is not clear, but the accuracy of measurement at such a low retention period (10 minutes for the model) is not as high as for longer periods."

Discussion.—Following the presentation of the paper by Mr. Windridge, the co-author, Mr. Clifford, in added remarks emphasized the complication of factors that influence sedimentation efficiency in any tank. Among these are local eddies and mass movements, the energy of motion of the influent water which must be dissipated, the varying amount of suspended matter in the influent and temperature changes.

J. K. Hoskins

DISTILLERY WASTE AND ITS EFFECT ON THE TREATMENT OF SEWAGE AT STOCKPORT

By A. R. Ward

Journal and Proceedings, Institute of Sewage Purification, Part 1, 1935, pp. 199–204

This paper, presented at a meeting of the N. W. Branch of the Institute of Sewage Purification, April 5, 1935, is interesting if for no other reason in that it records a case in which the difficulties of treating a trade waste by the municipal plant forced the industry to abandon its location for one along the coast where the trade effluents could be discharged into estuarial waters.

This particular waste is the dealcoholized wort from the manufacture of alcohol from crude molasses by acid fermentation. The molasses, a by-product in the manufacture of sugar, is dissolved in water and acidified to 0.03 normal to form simpler fermentable sugars. After a definite time the liquor is further diluted, and yeast added in the proportion of 1 cwt. to each 3000 gallons.

The spent wort is discharged during distillation and contains proteins, potash, yeast cells and sulphuric acid. An analysis of the residue after evaporation indicates that it might be of considerable value as a fertilizer.

Potash as K_2O	29.95%
Phosphorus as P_2O_5	0.97%
Nitrogen	0.76%

Other by-products of the industry include acetaldehyde and fusel oil, approximately one part of the latter being obtained for every 1000 parts of ethyl alcohol. Typical analyses of samples of the waste taken from the equalizing tank are, in p.p.m.,

Oxygen absorbed in 4 hours from N/80 $KMnO_4$	12,280 *	15,920 *	14,880 *
Solids, total	44,254	33,278	43,089
Solids, suspended	1,984	1,185	1,840
Solids, suspended, volatile	1,704	1,025	1,560
Solids, dissolved	42,270	32,093	41,249
Solids, dissolved, volatile	30,495	23,975	29,934
Saline ammonia (as N)	44.8	24	43.2
Albuminoid ammonia	344	250	221
Total nitrogen	—	610	—
Acidity (as H_2SO_4)	3,038	6,370	3,822
Sulphur as sulphate	—	767	—
Sulphur, organic		49	

* B.O.D.—approximately 60 per cent of these figures.

The difficulties created by this waste in the municipal treatment plant were first appreciated when the process was changed from inefficient chemical precipitation and land disposal to the bio-aeration method. Following experimental evidence of impending trouble, the industry was required to equalize the flow of its trade effluent in such a way that the 194,000 gallons per week was discharged in proportion to the sewage flow. Even with this distribution, it is estimated that, on an oxygen demand basis, this quantity is equivalent to the sewage from 128,000 people. Other analytical data are given to show the preponderating affect of this particular waste when added to the municipal sewage.

Numerous efforts were made to partially treat the waste at the plant. No known precipitant had any effect without dilution to at least six times the bulk. Chlorine had little effect, and "Actibon" soon weakened in its activity. Moreover, aluminoferric added in the bioaeration units produced disastrous results due to the reduction of sulphates to sulphides. Chemical experts could suggest no method by which these wastes liquors could be made more amenable to treatment and an enormous additional expense was involved in enlarging the municipal works. Ultimately, after all possible corrective procedures had been explored and found impracticable, and after other inland towns had denied it access to sewers, the industry abandoned its plant and relocated on the seacoast. Since that time the tank effluent at the municipal treatment plant is only half the strengh it was previously and odors are absent.

The author considers that exclusion of this waste from the sewer system was entirely justified and that the town took the only course available. He presents evidence to show that any other biological scheme of treatment would have been equally adversely affected and would have necessitated similar action.

J. K. Hoskins

RIVER POLLUTION BY TRADE EFFLUENTS

By Dr. A. Parker

Lecture before the Bristol (England) and South Western Counties Sections of the Society of Chemical Industry and abstracted in *The Surveyor*, **88**, 681 (December 13, 1935).

Pollution equivalents of industrial wastes and studies of sewage treatment and disposal methods by the British Department of Scientific and Industrial Research are reviewed by the author.

The average sized beet sugar factory discharges 3 to 4 m.g.d. of waste water with a polluting effect equivalent to that of several hundred thousand people. The total British sugar industry wastes are equivalent to the sewage from a population of several millions or nearly as much as the sewage from London. The wash waters from a milk collecting and distributing depot handling 10,000 gallons of milk daily contribute pollution equivalent to 1000 people, or for Great Britain the equivalent of 400,000 persons.

Research of the Water Pollution Research Board indicates that creamery wastes can be purified satisfactorily by ordinary oxidation processes and that, following simple preliminary treatment, beet sugar factory wastes can be reused, or if necessary be effectively purified on sprinkling filters.

Increasing populations, more intensive and changing uses of water in industry and agriculture are increasing the work of sewage disposal and the demand for water supplies of good chemical and bacteriological quality. Treatment methods for domestic sewage are available, though expensive, and can doubtless be improved by systematic scientific investigation, especially economical disposal of sewage sludge. Much work is ahead in developing satisfactory procedures for recovery of useful by-products and for the treatment of the varied industrial wastes resulting from new manufacturing processes.

J. K. HOSKINS

LEIPZIG MEETING, DEUTSCHEN GESELLSCHAFT FÜR BAUWESEN AND VEREIN DEUTSCHER CHEMIKER, APRIL 13, 1935

Reviewed by DR.-ING. HEILMANN

Gesundh.-Ing., 58, 190, 1935

UTILIZATION OF DOMESTIC SEWAGE AND INDUSTRIAL WASTES BY BROAD IRRIGATION

BY COUNCILLOR KREUZ

The use of sewage for agricultural purposes is of great assistance in producing foodstuffs high in protein, which Germany needs. According to Prüss the largest part of the constituents of sewage valuable for fertilizing purposes—52 per cent of the phosphoric acid, 75 per cent of the nitrogen and 80 per cent of the potassium—remains in the sewage after the removal of the solids by settling. Sewage should be purified on land when possible.

Sewage contains

.16 lbs. phosphoric acid per 1000 gallons or 1.6 lbs. per capita per year
.64 lbs. nitrogen per 1000 gallons or 6.4 lbs. per capita per year
.48 lbs. potassium per 1000 gallons or 4.8 lbs. per capita per year.

Only 50 per cent of the nitrogen is available for plant use so that the ratio of these substances is 1:2:3. Although formerly 1:2 was considered the best ratio of nitrogen to phosphoric acid, recent experiments have shown that the proportion of nitrogen should be higher so that the ratio of the fertilizing constituents in sewage is not far from optimum.

In order to produce the maximum yield of agricultural products the sewage from as many as 80 inhabitants can be distributed on an acre, if the grass is cut three or four times, the pasture well stocked and the sewage evenly distributed over the year. Undoubtedly the fertilizing constituents can be used to greatest advantage when the sewage is artificially sprinkled but this method has the highest operating cost and requires the largest amount of land.

In ordinary broad irrigation, land is divided into areas about 1.25 acres in size. This type of irrigation has several disadvantages: too much of the land is used for roads, dikes and ditches; the use of agricultural machinery is difficult; smoothing of the surface is expensive; cultivation of cereals has not proved satisfactory; and odors during the summer cannot be entirely avoided.

In another method of irrigation the water is held on plots of land 6 to 30 acres in size by dikes about 20 inches high. These plots are covered with sewage to a depth of 8 to 12 inches and allowed to stand from 3 to 6 days in summer and about a week in winter. The water remaining after that time is drained off through ditches. The dis-

tribution on land with at least a two per cent slope has also proved very satisfactory.

The same principles apply in the use of both industrial wastes and domestic sewage for agricultural purposes. If not enough land is available the waste can be distributed on sloping land with treatment in fish ponds. The waste could also be treated by soil filtration, with agricultural use of the land in the second year, so that half the area would serve for sewage treatment and the other half would be used intensively for agricultural purposes in combination with sewage fish ponds. In general, separation of wastes injurious to plant life is not recommended because the treatment of injurious wastes alone is usually very difficult and when the injurious and non-injurious wastes are mixed the injurious ones become neutralized and do not harm plant life.

THE SPRINKLING OF DOMESTIC SEWAGE AND INDUSTRIAL WASTE

By Dr. Gunther Schonnopp

Sprinkling is the best method of using sewage for agricultural purposes. An average annual addition of 10 inches of sewage for normal agricultural operations amounts to 271,300 gallons per acre or the sewage from 15 to 20 persons per acre. With light frosts the sewage can still be sprinkled but with a heavy freeze it should be irrigated with pipes. By-passing is necessary only during very heavy storms. The preliminary treatment should be as simple as possible. Usually screens and grit chambers are sufficient but occasionally simple settling tanks should be used.

SEWAGE PURIFICATION IN FISH PONDS

By A. Schillinger

The Munich sewage fish ponds consist of an area of about 575 acres, of which about 494 serve for the raising of carp, tench and trout and for the biological treatment of the sewage of Munich. The remainder of the area is necessary for raising the young fish and for holding fish over the winter. The sale of large amounts of fish in the fall must be avoided because of the danger of depressing the market price. In Munich the fish are stored and can be supplied to the market throughout the year. Fish ponds require only about one-tenth the area necessary for broad irrigation and produce at least as good, if not a better, effluent. However, fish ponds can be used only where sufficient dilution water is available. Not less than three parts of pure water are necessary to one part of clarified sewage. The price of land must not be too high and it should be in such condition that the cost of preparing it for ponds will not be too great. The amount of sludge depositing in the ponds is relatively small. After five-years' operation the sludge layer, except in the drains, was very shallow, when the ponds were drained.

At ordinary temperature one acre of pond will treat the sewage from about 810 persons. Heavier loads can be handled but not economically. The detention period of the sewage should be about two days and the velocity should be low enough to prevent the plankton from being washed out. About 400 pounds of fish can be obtained annually from one acre. The most favorable pH for sewage purification and for raising fish is between 7.2 and 8.0.

THE UTILIZATION OF SEWAGE CONTAINING OIL AND FAT

By Dr.-Ing. A. Heilmann

Since Germany must import a large amount of fat an effort should be made to recover as much as possible from sewage and industrial wastes. The removal of fat from sewage eliminates the clogging of pipes, improves the sludge as fertilizer and decreases the load on rivers. Since the installation of about 1000 grease traps in Cologne, Duisburg, Wuppertal and Düsseldorf, about 33 millions pounds of grease have been obtained and 23.1 million pounds of soap have been produced. Industrial wastes from wool scouring plants, margarine industries and slaughter houses are particularly

high in fats. A large amount of raw fat can be obtained from sewage but the problems of recovery cost and utilization have not been worked out.

THE UTILIZATION OF WASTES FROM SUGAR, STARCH, CELLULOSE, PAPER, TEXTILE AND BREWING INDUSTRIES

By Prof. Dr. H. Haupt

The lanolin and suint salts should be recovered from wool scouring wastes. Potash free from iron and valuable for glass manufacture may be obtained by evaporation of the steep and wash water and ignition of the residue. The wool fat may be recovered by acid or caustic potash precipitation.

In cotton, flax and jute spinning mills, better efficiency can often be obtained by re-using the alkaline liquors for cooking the yarn. The total waste of the yarn bleacheries can be purified by broad irrigation after mechanical clarification and aeration. The experiments on recovery of dyestuffs from dye wastes have not yet been successful.

In the wheat starch industries the soluble wheat protein should be recovered, all substances valuable as food should be removed, the fresh gluten made into shoemakers' glue and the remaining waste purified by broad irrigation.

In breweries all solid substances such as yeast residues, spent malt and hops should be recovered for their food value. In rural breweries broad irrigation on meadow land is recommended.

The sugar industries have recently done a great deal to improve their wastes by recovery processes. The sugar residues in the molasses have been concentrated, the fertilizer value of the sludge has been increased by treatment with lime and much of the heat from part of the waste has been conserved.

The modern fibre recovery plants in the paper industry make possible the re-use of the fibre and kaolin in the industry itself. Recently, the small amount of aluminum sulphate residue has been used as an aid in coagulating the raw waste.

Since 50 to 65 per cent of the dry weight of wood is dissolved in the cook-liquor during the production of cellulose, enormous amounts of materials are lost; an economic development of the greatest importance will therefore come with the utilization of this waste product. At present, about 1.2 to 2.0 per cent of the fermentable sugars are converted into alcohol.

THE UTILIZATION OF WASTES FROM TANNERIES AND SLAUGHTER HOUSES

By Dr. R. van der Leeden

The recovery of sulphur from tannery wastes requires special equipment which can be operated continuously and economically only with difficulty, because of lack of space and operating personnel and because of the small yield of sulphur. The larger part of tannery wastes cannot be discharged into a stream but should be purified by broad irrigation. The recovery of chromium salts is profitable but it requires a change in operation of the tannery because considerable amounts of liquor which are usually handled as sewage must be clarified and filtered. Space and personnel for this are usually not available and it can only be decided by local conditions whether such an operation can be carried out.

At the Neumünster clarification plant about 8500 cubic feet of fresh sludge with 96 per cent moisture resulted from the common precipitation of tannery and municipal sewage. The sludge, which contains about two-thirds organic matter, should be incinerated because of the danger of anthrax. The sludge may be dewatered by a Schmidt filter which draws off the water without pressure or by centrifugal force.

The equipment in slaughter houses is generally unsuitable for collecting blood and it frequently clogs the sewers, becomes septic and cannot be controlled, even with large amounts of chlorine. One of the most satisfactory methods of recovery is to draw the blood by vacuum directly from the veins of the animal. The stomach contents of cattle can be used for hog food after they have been dried in a vacuum.

THE UTILIZATION OF SLUDGE AND OTHER VALUABLE MATERIALS FROM THE COAL INDUSTRIES

By D. H. Wiegmann

The wastes resulting from the production of oil and bituminous materials from coal always contain poisonous substances which may injure streams. It is economical to remove from the waste only such substances which, obtained in pure form, either have a definite value or those which are so easy to recover and so simple to work over that the cost of production is practically nil. For example, the recovery of slack from the coke quenching liquor permits the quenching water to be re-used. Phenol, the most poisonous constituent of wastes from low temperature coking and by-products plants, is present in such concentrations that its recovery is profitable. The consumption of phenol, which is always increasing, could hardly be satisfied last year by German production.

THE REMOVAL AND UTILIZATION OF SOLIDS FROM MUNICIPAL SEWAGE

By Director Mieder and Dr. Viehl

Screenings make good fertilizer but because of the high paper content they should be composted before use. With proper seeding, decomposition of the organic constituents proceeds rapidly. Grit is valuable only if the sand is nearly free from light organic substances.

Fresh sludge should be digested in heated digestion tanks to make it dry rapidly and to destroy the seeds of weeds which are present in raw sludge. For digestion the sludge must be neither too dry, since it mixes with difficulty and digest poorly, nor too wet, for that necessitates too large digestion capacity. Digested sludge is not only a good fertilizer but because of its humus content is suitable for making waste land tillable. The high water content makes its transportation expensive and complete drying with heat is not economical. Dry distillation or burning, with or without briquetting, has not been successful. The treatment of fresh sludge with acid, lime or iron for partial removal of water is also too expensive. By centrifuging, the sludge can be dried rapidly, but the large quantity of turbid liquor which results requires special treatment.

By mixing wet, usually alkaline, fresh sludge with peat which has an acid reaction there results, after partial dewatering, a fertilizer called "Biohum" which should be as good as rotted manure on arable soil. As "Biohum" contains a large amount of humus matter it can be used to improve soils lacking in humus.

G. P. Edwards

PRIMARY TREATMENT PLANT INCLUDES MAGNETITE FILTER

By W. S. Bemis

Engineering News-Record, **115**, No. 5, December 19, 1935, pp. 852–55

Gross pollution of the Elkhart River made partial treatment at Goshen, Indiana, necessary but due to the discharge of untreated wastes from cities downstream, complete treatment seemed inadvisable. The sewage treatment plant design, therefore, includes pumping station; 1 inch opening screen with shredder and a supplementary 1¾ inch hand raked bar screen; grit remover with a proportional weir to maintain a constant velocity of sewage going through the chamber for all volumes of flow; 45 ft. diameter by 10 ft. side water depth primary settling tank with rotary sludge scrapers and a 6 ft. wide automatic magnetite filter; separate sludge digestion with collection of gas for heating the digestion tank and buildings; and sludge drying beds.

The use of a magnetite filter gives an expected additional 25 per cent removal of suspended solids at a reasonable cost. The plant effluent line forms a continuation of the incoming intercepting sewer, the 14 ft. pumping lift caring for losses in head through the plant and enabling the units in the plant to be placed above high water.

R. W. Kehr

DOMESTIC AND PACKING-HOUSE WASTES TREATED JOINTLY AT CEDAR RAPIDS

ANON.

Engineering News-Record, 115, No. 24, December 12, 1935, pp. 803–807

The plant receives a total flow of 6.5 m.g.d. with an average B.O.D. of 246 p.p.m. from a present population of 60,000. The design allows 17 per cent for increase during the next ten years in units easily expanded, such as clarifier and filters, while units difficult to expand are designed for a 1970 population of 170,000. In addition to the 6.5 m.g.d. there are 1.2 m.g.d. of packing-house wastes with an average B.O.D. of 2000 p.p.m., which are given separate primary treatment.

The packing-house waste is screened with 40 mesh screens and the grease removed at the packing plant then pumped through a 14 inch pressure line to a storage tank 70 ft. diameter by 12 ft. deep, which balances the flow and discharges through a rate of flow controller to a cone and cylinder air blown grease removal unit. From there the waste goes to a fresh mixer where sulphuric acid is added for alkalinity control and ferric chloride for coagulation. Next it passes to a flocculator, then secondary clarifier, then to a clearwell to be pumped to the filter dosing tanks of the main plant.

The city sewage reaches the plant through one 42 inch interceptor and two 20 inch east iron siphons under Cedar River. It is first screened through a ¾ in. bar screen, mechanically cleaned, with incineration of the screenings in a gas fired incinerator. The screened sewage is then pumped through a rising well and a channel with an overflow by-pass to the grit chamber which is equipped for mechanical removal and washing of the grit. Following air agitated grease removal, the sewage flows to an octagonal radial flow clarifier during low flows with four straight line clarifiers in addition for handling larger flows. There are eight circular trickling filters, each 167 ft. in diameter, 6½ ft. deep, fed from twin dosing tanks. Variation in delivery to the beds is held to an average of 1.2 per cent by variation in spacing and size of orifices on the different clarifier arms. The eight filters are served by two pairs of final straight line clarifiers 73 ft. long with a novel sludge removal mechanism which consists of channels cast in the floor at 11 ft. intervals and covered by a rubber faced apron on the scrapers for a short interval during which movement of the flight operates a quick opening valve which flushes the sludge into a center gallery.

Careful attention is paid to odor control. The packing-house balancing tank is washed with effluent after it empties, the detention period of the primary clarifiers can be shortened during low night flows and provision has been made to apply chlorine for controlling odors.

All sludge is pumped to 3 digestors which are interconnected for series or parallel operation, heated by engine cooling water, and one of which is covered by a 60,000 cu. ft. gas holder. A fourth tank is open and serves as a sludge storage tank prior to conditioning with ferric chloride and vacuum filtration, or drying on reserve sludge drying beds. An automatic 150 kw. gas engine generator furnishes power for normal requirements, including pumping and some excess which is metered back into the local utility power circuit.

Contractors bidding on units of the work did not include the cost of mechanical equipment in their bid, as alternate bids were obtained from the various manufacturers for this equipment.

R. W. KEHR

OPERATION OF YORK TOWNSHIP PLANT

BY C. CHAMBERLAIN,

Plant Supt., Toronto, Ont. Canadian Engineer, 69, No. 16 (Oct. 15, 1935)

The York Plant was built in 1925. It now serves 65,000 people with a D.W.F. of 2½ m.g.d. The solids in the sewage average 500 p.p.m.

The plant consists of 1½ inch bar grates, grit chambers, 4-hour aeration tanks, 3-hour Dorr settling tanks, sludge reaeration channel, vacuum filters (2 — 8 × 8½ ft. FEine) and storm tanks (up to 90 c.f.s.).

Average daily operating data are: air used 1.5 c.f. per gal., sludge return 29 per cent, excess sludge 35,000 gals. 2 per cent solids, ferric chloride conditioner 650 lbs., filter cake 25 cu. yds. 84 per cent moisture, 14 hour filter run, grit 1½ cu. yds., screenings 1½ cu. yds. Sludge from the storm water tanks is 25 per cent organic.

FRANK TOLLES

OPERATION OF KITCHENER SEWAGE DISPOSAL PLANTS

BY STANLEY SHUPE, *City Engineer*

Canadian Engineer, **69**, No. 16 (Oct. 15, 1935)

Kitchener has two plants. The Main Plant includes bar grates, detritor, settling tanks, separate sludge digestion with gas recovery and covered drying beds. The smaller plant is an activated sludge plant with bar grates, detritus tanks, "Rotary Fine Screen Aeration," reaeration, clarification and lagooning of sludge. Data for each plant follow:

	Activated Sludge	Main Plant
Built	1925	1930–31
Cost	$70,000	$326,000
Capacity	1 m.g.d.	4 m.g.d.
Present flow	0.8 m.g.d.	3.7 m.g.d.
Degree of treatment	86%	57%
B.O.D., reduction, 5 day	92%	39%
Operating personnel	2	9
Operating Costs 1934		
Labor	$2,264.26	$11,115.62
Power	2,514.47	463.59
Mts. supplies, maint. and repairs	982.35	2,097.96
	5,761.08	13,677.17
Operating per m.g.	19.72	10.71
Capital per m.g.	15.39	17.92
Annual cost per m.g.	35.17	28.63

Operating Results

Screenings per day—wet	1,475 lbs.
dry	447 lbs.
Detritor solids—per day wet	4,000 lbs.
dry	684 lbs.
Clarifiers—sludge per day	14,800 gals.
solids	5.8%

FRANK TOLLES

NORTH TORONTO SEWAGE TREATMENT WORKS

By George Phelps, *Engineer of Sewers, Department of Works, Toronto, Ont.*
Canadian Engineer, 69, No. 16 (Oct. 15, 1935)

The activated Sludge plant at North Toronto has a capacity of 7½ imp. gals. daily. Twice the D.W.F. is treated through the full process and all storm flows are settled. The plant includes:

Bar grates mechanically raked.
Grit chambers with proportional weirs. Grit is washed.
Preliminary sedimentation tanks for two hour detention. Removal mechanism is Dorr equipment which is controlled automatically by telechron devices.
Aeration tanks for six hour detention with 6 pound air applied through two rows of aeration plates.
Final settling tanks for 5 hour settling and with mid-tank launders for removal of effluent. Removal equipment is Hankin.
Sludge digestion tanks
Covered drying beds provided with unit heaters.
Storm water tank which provides 5 mins. detention for max. flow. Sludge is discharged to the main works.

Frank Tolles

REFERENCES TO SEWAGE LITERATURE

(December, 1935 and January, 1936)

Water Works and Sewerage.

December, 1935:

"The Menominee Falls, Wisconsin, Activated Sludge Sewage Treatment Plant." R. Cramer, Jr. Pp. 418–421.
"A Modern Turbidimeter." G. Laughlin. P. 423.
"The Patent Situation in Sewage Treatment." P. Hansen. Pp. 425–426.

January, 1936:

"The 'Odeeometer'—Its Place in the Control of Activated Sludge Plants." L. H. Kessler. Pp. 13–19.
"New Jersey Department Liberalizes Sprinkling Filter Requirements." P. 23.
"Chemical Sewage Treatment for New Britain, Conn." P. 25.
"Schenectady Plans to Enlarge Sewage Treatment Plant." P. 25.
"Hourly Load Variations in Relation to Sewage Treatment Plant Operation." E. T. Killam. Pp. 26–27.

Engineering News-Record.

December 5, 1935:

"Sewerage and Sewage Disposal in a South African Town." P. 779.
"Trade Waste Treatment at Beltsville Research Center, Maryland." Pp. 787–788.

December 12, 1935:

"Domestic and Packing-house Wastes Treated Jointly at Cedar Rapids." Pp. 803–807.

December 19, 1935:

"Primary Treatment Plant Includes Magnetite Filter." W. S. Bemis. Pp. 852–855.

January 2, 1936:

"Sewage Treatment Trends in England." K. Imhoff. Pp. 8–11.

January 9, 1936:

"Pre-Tagged and Spotted Milk Bottles Expedite Sewage Sampling Procedure." P. 39.

"Mine Sealing Program to Reduce Acid Pollution in Streams." Pp. 42–43.

"Activated Sludge Plant Replaces Sprinkling Filter at Columbus, Ohio." P. 51.

"Cleveland Adds a New Plant to its Sewage-Disposal Facilities." Pp. 52–58.

"Sewage Plant Wins Suit Over Odor Nuisance." P. 68.

January 16, 1936:

"Sludge Sedimentation at Los Angeles, Calif., Plant." P. 107.

January 23, 1936:

"Sewage-Sludge Incinerator Introduced at Calumet." W. A. Dundas. Pp. 116–119.

January 30, 1936:

"Milwaukee Extends Facilities for Sewage Treatment." D. W. Townsend. Pp. 153–157.

Public Works.

December, 1935:

"Designing and Construction Costs of Storm Sewer in Allentown, Pa." E. W. Meckley. Pp. 9–11.

"Rainfall Records for Planning Storm Sewers." Pp. 20–22.

"Sewage Treatment as a Business." P. 35.

January, 1936:

"Hints for Winter Operation of Sewage Plants." P. 14.

"Activated Carbon Aids Sludge Digestion at Liberty." J. Lawrence and H. Eichenouer. P. 17.

"Cost of Operating Geneva Treatment Plant." P. 17.

Municipal Sanitation.

December, 1935:

"Attractive Design of Small Plant (Fairhope, Ala.)" F. N. Williams, Jr. Pp. 362–364.

"State Planning Boards Review Losses from Stream Pollution." P. 364.

"Sprinkling Filter Operations Outlined by Jersey Officials." Pp. 376 and 384.

"Novel Sewer Installations at Mountain View (Calif.)." P. 382.
"Disease Bacteria Absent in Fertilizer Made from Sludge." P. 382.
"Improved Centrifuge Tested in Dewatering Sludge." I. Gutman. P. 386.

January, 1936:

"Some Interesting Tests on Chemical Precipitation." N. G. Damoose. Pp. 8–13 and p. 28.
"The Outlook in Sewage Treatment." C. A. Emerson, Jr. P. 14.
"Corrosion Studies Develop Some Interesting Data." J. A. Meacham. Pp. 15–17.
"Sanitation District vs. Local Plants." A. D. Weston. Pp. 18–19 and p. 25.
"An Interesting Experiment in Reducing Plant Odors." W. J. Schiverea. P. 26.

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